Exploring Real Options in the Capital Budgeting of Investments within Physical Asset Management

by

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Thesis presented in partial fulfilment of the requirements for the degree of Master of Engineering Management at Stellenbosch University

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Declaration

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Abstract

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This study explores the implementation of an integrated capital budgeting visual mapping framework comprised of both Discounted Cash Flow (DCF) and Real Options Analysis (ROA) techniques. Physical asset investment decisions are based largely on rigid discounted cash flow tools which provide untimely and incomplete decisional criteria. While literature outlines the wide spread use of traditional DCF techniques, it very openly reveals large limitations, including its static inflexibility and slow to evolve framework. ROA is a more recent valuation tool based on stock option theory. It brings into account added value found in the flexibility of managerial decision making and uncertain conditions. This study implements a combined DCF and ROA capital budgeting tool within a Physical Asset Management (PAM) environment. The validity of the framework is realised through an industry relevant case study presented by a South African mining company.

Uittreksel

Die Ondersoek van Reële Opsies in die Kapitaalbegroting van Beleggings in Fisiese Batebestuur

"Exploring Real Options in the Capital Budgeting of Investments within Physical Asset Management"

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Hierdie tesis ondersoek die toepassing van 'n geïntegreerde visuele kapitaalbegrotingafbeeldingsraamwerk wat uit verdiskonteerde kontantvloei en reële opsie–analise bestaan. Fisiese batebeleggingsbesluite is dikwels gebaseer op rigiede kapitaalbegrotingstegnieke wat onvolledige besluitnemingsmaatstawwe aanbied. Terwyl literatuur die wydverspreide uiteensetting van verdiskonteerde kontantvloei openbaar, is daar nog steeds baie beperkings, soos die onbuigsaamheid en die stadige ontwikkelingstempo van verdiskonteerde kontantvloei–analise. Reële opsie–analise is 'n meer onlangse waardasiemetode wat op aandelemarkfinansies gebaseer is. Reële opsies word addisionele waarde bygevoeg deur die onsekerheid en buigsaamheid van fisiese batebeleggings. Hierde tesis implimenteer 'n gekombineerde verdiskonteerde kontantvloei en reële–opsie kapitaalbegrotingmetode binne 'n fisiese batebestuur omgewing. Die geldigheid van die gekombineerde metode is getoets met behulp van 'n gevallstudie beskikbaar gestel deur 'n Suid Afrikaanse myn.

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The Author
December, 2012

Dedications

This thesis is dedicated to family and friends,
for their continued understanding, patience and love.

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Acronyms and Abbreviations

ACRG	Asset Care Research Group
AMS	Asset Management System
ARR	Accounting Rate of Return
BLM	Binomial Lattice Methods
BS	Black–Scholes
BSI	British Standards Institution
CAPM	Capital Asset Pricing Model
CE	Certainty Equivalent
CEF	Certainty Equivalent Factor
CE(NPV)	Certainty Equivalent Net Present Value
CPI	Consumer Price Index
CV	Coefficient of Variation
DCF	Discounted Cash Flow
DTA	Decision Tree Analysis
EVA	Economic Value Added
FV	Future Value
GBM	Geometric Brownian Motion
GM	General Motors
HBR	Harvard Business Review

IAM	Institute of Asset Management
IRR	Internal Rate of Return
NPV	Net Present Value
PAM	Physical Asset Management
PAMS	Physical Asset Management Strategy
PAS 55	Public Available Specification 55
PB	Payback Period
PI	Profitability Index
PV	Present Value
RADR	Risk Adjusted Discount Rate
RADR(NPV)	Risk Adjusted Discount Rate Net Present Value
ROA	Real Options Analysis
ROV	Real Options Valuation
RSA	Republic of South Africa
WACC	Weighted Average Cost of Capital

Notation

r_b	Adjustment for normal business risk
r_p	Adjustment for the risk on a specific project
u	Binomial lattice up factor
d	Binomial Lattice down factor
CF	Cash Flow
CEC_0	Certainty equivalent coefficient of the initial investment amount
CEC_t	Certainty equivalent coefficient of the cash flow in period t
K_{d}	Cost of debt
K_{e}	Cost of ordinary equity
Φ	Cumulative standard normal distribution
r	Discount rate
q	Dividend
X	Exercise price
tr	Marginal company tax rate
D	Market value of debt
E	Market value of ordinary equity
V	Market value of the firm
n	Maximum time period
Rm	Rand Millions
r_d	Risk adjusted discount rate
r_f	Risk-free rate

p	Risk neutral probability
σ	Standard deviation
∂t	Step size
S	Strike price
β	The Beta of a share
t	Time period
k_r	The return required by equity holders
R_m	The return on the market portfolio
σ^2	Variance

Chapter 1

Problem Statement

1.1 Introduction

Businesses are continually confronted with the problem of determining whether the future returns of current investments will be profitable. Will an investment yield an acceptable rate of return rendering a project profitable? The term investment refers to the outlay of resources in acquiring or creating an asset with the intention of generating future profits. Capital budgeting is the process whereby organisations evaluate potential investments.

The capital budgeting decision is essential as an organisations future financial success will depend on current investment decisions. The investment type can range from the acquisition or creation of tangible assets such as plant and equipment to intangible assets such as a new product marketing launch. Organisations are constantly investing in various sectors in order to remain competitive in a constantly changing business environment. In most cases the investment decision requires significant funding and thus has a material impact an organisations overall strategic objectives.

Figure 1.1 presented below illustrates the primary considerations of capital budgeting and the investment decision. The cost of capital refers to the cost associated with the means by which an investment will be financed. The other side refers to the returns generated by an investment. In order for an investment to be profitable (and thus acceptable) it must generate return in excess of the costs associated with the means by which it has been financed. Maximum value is achieved when costs are minimised and returns are maximised.

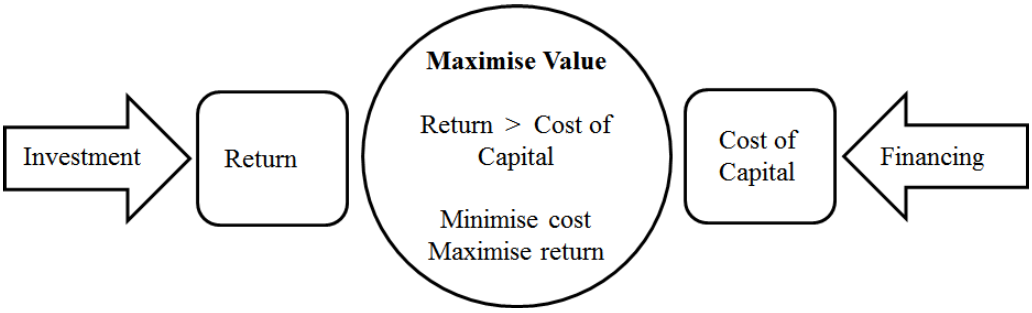

Figure 1.1: Maximising investment value

Two fundamental variables that make investment and financing decisions complex are timing and risk. The uncertain future decisions made today ultimately have an effect on the future actions and outcomes of tomorrow: it is thus crucial that effective decision making tools are employed that take risk and timing into account. Capital budgeting under risk and timing is a challenging task as there is always a struggle between risk, timing and most importantly the return on an investment. The risk-return trade-off under uncertainty influences many decisions, ultimately firms are looking to achieve the highest conditions of returns with the lowest possible risk. Any effective capital budgeting plan takes into account four basic factors:

i) Present value

ii) The time value of money

iii) Risk and return

iv) Asset class

Present value

The Present Value (PV) concept is crucial as it allows the organisation to determine today's value of expected future cash flows. It is important as it allows for the comparison of different cash flows[1] which occur at different times in the future. This is based on the premise of active capital markets where *discount*

[1] Accounting profits do not always reflect cash flows. Profits are determined by the organisations accounting policies, whilst corporate finance is based on cash flows explains Correia and Wormald (2011)

rates and *inflation* are directly applied.

Inflation refers to an increase in average prices in an active economy over a period of time. This means that the general price level of goods and services rises which results in the erosion of purchasing power of money. The measure of price inflation is called the inflation rate and is measured annually as a percentage of the general Consumer Price Index (CPI) over time. An investments PV is calculated using the *discount rate* also known as the cost of capital. This is a percentage rate made up of both the cost of debt and the cost of equity. The discount rate will include the inflation premium as investors gear themselves against the reduction in purchasing power of money.

Time value of money

The time value of money concept further reinforces the value of cash flows under the premise of discount rates. The value of the investment is determined by not only the size of future cash flows but also the timing of cash flows. Investors prefer to receive cash flows sooner, rather than later as cash flows received earlier can be reinvested to earn a return. By using a discount rate on cash flows over a prescribed period of time, will result in the calculation of the PV which will distinguish the time value of money. This highlights the basic principle that a rand earned today is worth more than a rand earned tomorrow.

Risk and return

Investors will expect to earn returns that are correlated to the amount of risk they are exposed to. It is important that investments yield an acceptable level of return for the amount of risk that investors are exposed to. The acceptable level of risk will depend on an organisations risk appetite. The discount rate used to determine the PV of the investment will incorporate a risk adjustment factor. In simplifying this concept, a rand earned today is worth more than a rand earned tomorrow and a certain rand is preferred to an uncertain rand.

Asset class

Although all investments are evaluated on the same PV basis, there are two main types of investment asset classes: tangible and intangible assets. Tangible assets include real, physical items such as property, plant and equipment while intangible assets include investments which cannot be seen or physically touched such as human capital, marketing campaigns and intellectual property. This study focuses specifically on tangible and real *physical assets*, this means investments specifically in the creation or acquisition of investments such as buildings, vehicles and equipment.

1.2 Physical Asset Management

As outlined in the *Asset class* section, the study proposes to investigate the capital budgeting of tangible and physical assets. A physical asset can be defined as plant, machinery, property, buildings, vehicles and other items which carry distinct value. The subject of Physical Asset Management (PAM) is the framework supporting the overall life-cycle of an asset, from the acquiring and creating of assets, through to the effective implementation and disposal of assets. Due to the increased complexity in the management of physical assets and in response to an increasing demand from industry for a standard specification, the Public Available Specification 55 (PAS 55) was published in 2004.

The PAS 55 framework was initiated by the Institute of Asset Management (IAM) and the British Standards Institution (BSI) in efforts to portray key PAM requirements as a more structured standard. The premise of PAS 55 is that without key PAM standards an organisation's asset management systems are deficient and incomplete. To enable full PAM functionality, PAS 55 integrates four key asset classes directly related to physical assets. These assets classes are: human assets, financial assets, information assets and intangible assets. One such area of significance presented in Figure 1.2 is the interface between *Financial Assets* and *Physical Assets*. Here a key objective according to PAS (2008) is the capital investment criteria which deals specifically with the acquisition and creation of physical assets. It is within this critical enhancement interface within the PAS 55 scope that the research for the study was formulated.

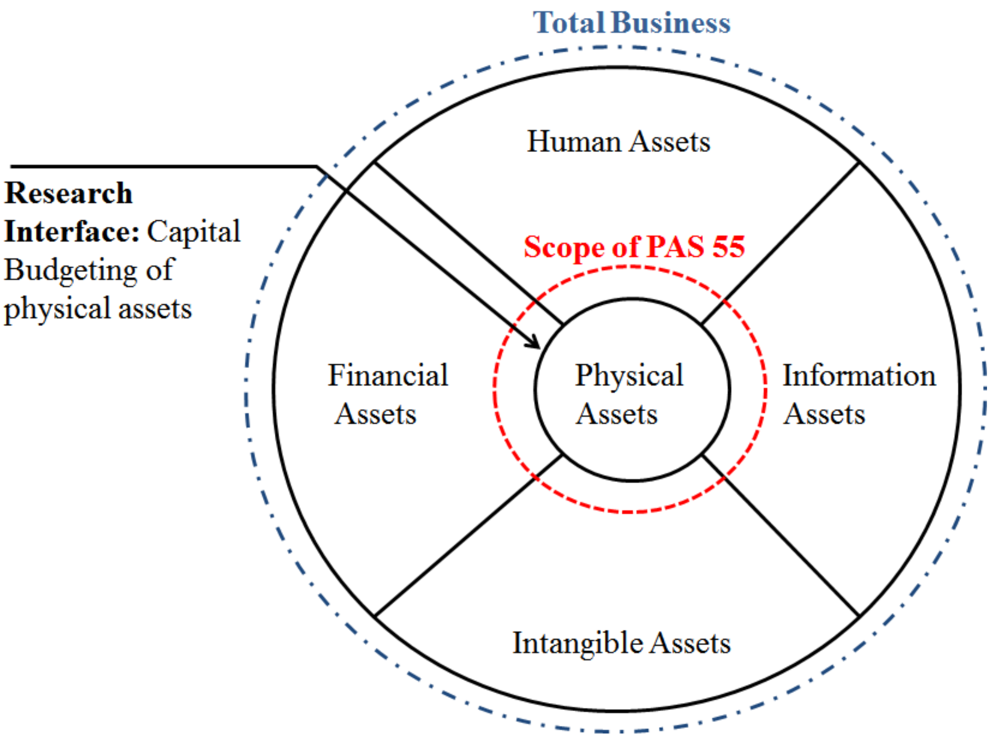

Figure 1.2: Research focus area in relation to PAS 55 asset classes
Adapted from PAS (2008)

1.2.1 Research Formulation

This studies research formulation is based on the integration between the Financial and Physical Asset classes within a PAM framework, such as the scope of PAS 55 shown in Figure 1.2. The study investigates the viability of implementing a supplementary capital budgeting technique in the creation or acquisition of physical assets. By arguing that current capital budgeting techniques employed lack depth and flexibility, this study implements new capital budgeting decision tools to enhance the successful acquisition or creation of physical assets.

1.3 Capital Budgeting Techniques

As previously mentioned, capital budgeting takes into account two primary elements in the valuation of investments: risk and timing. Not surprisingly, many tools, methods and mechanisms have been developed over time to account for risk and timing. To date, the most widely implemented capital budgeting tools are Discounted Cash Flow (DCF) methods. DCF analysis uses the concept of the *time value of money* to evaluate a projects profitability. This is done using a suitable discount rate based on the cost of capital to finance an investment based on the premise of future returns (cash flows). The capital budgeting techniques addressed in this study are listed below:

i) Payback Period (PB)

ii) Net Present Value (NPV)

iii) Internal Rate of Return (IRR)

iv) Certainty Equivalent (CE)

v) Risk Adjusted Discount Rate (RADR)

vi) Real Options Analysis (ROA)

The PB method explains the most basic of capital budgeting techniques which does not discount future cash flows. The NPV and IRR methods are of the most popular DCF methods integrated in firms in evaluating the profitability of investments. The CE and RADR methods listed are based on conventional DCF assumptions however they are theoretically more flexible in accounting for risk investments using risk-adjustment tools. The final technique listed is ROA and serves as a core research area within this study. ROA is a capital budgeting tool based on financial stock option theory. More on ROA is covered in this introduction as well as the study.

1.3.1 Discounted Cash Flow Techniques

The two most commonly used Discounted Cash Flow (DCF) techniques which use the concept of time value of money are Net Present Value (NPV) and

Internal Rate of Return (IRR). The Profitability Index (PI)[2] is a further derivation of NPV and is often seen as a *benefit/cost ratio.*

Net Present Value

The NPV capital budgeting technique takes the time value of money into consideration. The NPV of an investment is the sum of the discounted cash flows less the sum of discounted investment costs. This is illustrated in Equation 1.1 below. If the NPV is zero, then the returns on the investment are equal to the discount rate, however should the NPV be greater than zero then the return rate of the investment is higher than the discount rate and the project adds value. This is a positive scenario and if NPV is greater than zero the investment is exercised. If the NPV is less than zero, the investment does not create value and thus not exercised.

$$NPV = \sum_{t=1}^{n} \frac{CF_t}{(1+r)^t} - X \tag{1.1}$$

Where, r = discount rate, CF = cash flow, n = maximum time period, X = Cost of the investment and t = Time period.

1.3.2 Shortcomings of Discounted Cash Flow Techniques

The appeal of DCF techniques stems from the simplicity with which capital budgeting can be applied to investments. The calculation uses a discount rate which takes into account all associated risks. Using the PV method and the time value of money, future cash flows are then discounted based on the risk factored discount rate. The result of the NPV calculation is just as simple to interpret. If the NPV is greater than zero, the investment adds value and thus the decision is exercised. Should the NPV be less than zero, the investment is not exercised. In principle NPV uses a single metric, which results in a two decisional criteria which is either, *invest* or *don't invest.* This simplicity has led to its widespread adoption as well as utilisation. According to a thorough survey published by Graham and Harvey (2001) consisting of 392 CFO's from

[2]The PI is often used by organisations when rationalising investment decisions

firms in the US and Canada it showed that 75% of firms CFO's are always using NPV in capital budgeting decisions.

Conversely the simplicity of DCF calculations, is also its downfall as a capital budgeting technique. There are five key issues dampening the significance of DCF techniques such as NPV and IRR and they have evolved due to the rigid nature of the techniques themselves. The single figured risk adjustment discount rate (r) is both inflexible and lacks sufficient depth. It uses one rate to account for all the uncertainty present in an investment decision. These deficiencies will be covered in more detail in the study, nevertheless, five key issues are mentioned here:

i) The comparison of investments and projects with unequal lives.

ii) Inadequate adaptation of inflation in capital budgeting.

iii) Capital constraints causing the rejection of positive NPV investments.

iv) Ineffective utilisation of assessed tax losses.

v) The ineffective valuing of abandonment options and optimal economic lives.

Although financial theory supports DCF techniques in assessing the viability of capital budgeting projects and investments, DCF techniques do have limitations. Authors such as Trigeorgis (1988, 1993) and Van Putten and MacMillan (2004), among others, suggest that traditional DCF methods do not account for decisional flexibility in the capital budgeting of projects.

The NPV method indicates that investment decisions should be based on either positive or negative NPV results. In real organisations, investment conditions and decisional criteria are far more complicated. Real investments often have integrated options within the decision making process which need to be considered on a management level. The NPV rule is not at fault, it is the responsibility of management to ensure future strategic options can be considered in the valuation of investments. In many cases, future investment opportunities or investment options are not included in the scope of DCF analysis and are lost or not considered. This hinders both the value of the proposed investment as well as disregards possible future opportunities.

1.4 Real Option Analysis

Real Options Analysis (ROA) is a financial tool with its roots in the valuation of stock market financial *options*. ROA applies option valuation techniques in the capital budgeting of investments. The core distinction between *real* options and *financial* options is that ROA considers real, physical and tangible assets as opposed to financial assets such as stocks. This makes it applicable as an investment decision tool in the realm of PAM. Two primary characteristics of ROA are its ability to account for value found in flexibility and uncertainty.

Real options can be seen as a capital budgeting approach consisting of financial theory, management and decisional science, statistics and economic modelling. It applies option theory in the valuing of real and physical assets and thrives in a flexible and uncertain business environment where strategic investment opportunities can be valued within a capital budgeting framework.

What are options?

Options are a form of derivatives which are traded in much the same way as *shares*. An option is the right to buy or sell an asset at some predetermined price at a particular time in the future. The option holds value as the investor has a right, but not an obligation to buy/sell the asset. In the case of purchasing the asset; if the *call option* has a higher value than the exercise price, then the investor can purchase the asset at a bargain price. A premium is paid by the investor to give him the option. Clearly then, in favourable conditions, the option is a valuable asset in the hands of an investor.

The *call option* is the price an investor buys the option at, call options are most profitable when the underlying asset value increases above the call option value. This serves to provide only an introduction to the definition of *options* and further information and examples are provided later in the study.

1.4.1 Option Pricing Models

Option pricing models are used to calculate the option value associated with an asset based investment decision. The option pricing models are used to evaluate the value inherent in the financial asset. In the study presented, two primary option valuation models are considered, they are:

i) The Black-Scholes Option Pricing Model

ii) The Binomial Option Pricing Model

Black-Scholes

The Black–Scholes (BS) equation was developed in 1973 by Fischer Black and Merton Scholes in their paper Black and Scholes (1973). The BS equation was created to value the option by sufficiently hedging the financial asset against proposed risks. The BS Equation 1.2 is presented below, along with its *financial* asset based parameters.

$$\begin{aligned}\text{BS call option value } = &S\Phi\left[\frac{\ln(S/X)+(r_f+\sigma^2/2)t}{\sigma\sqrt{t}}\right]- \\ &Xe^{-r_f(t)}\Phi\left[\frac{\ln(S/X)+(r_f-\sigma^2/2)t}{\sigma\sqrt{t}}\right]\end{aligned} \tag{1.2}$$

Where Φ = the cumulative standard normal distribution, X = Exercise price, S = Strike price, t = time, r_f = risk free interest rate and σ = standard deviation or volatility of the share price.

i) *Strike price.* The higher the strike price, the higher the value of the call option.

ii) *Exercise price.* The lower the exercise price, the higher the value of the call option.

iii) *Risk free rate.* An alternative investment portfolio hedging against factors such as inflation with a low risk profile, such as government bonds.

iv) *Time.* This refers to the amount of time the option has before it is exercised. The larger the time difference the larger the discrepancy in exercise prices.

v) *Standard deviation or volatility.* The greater the standard deviation the greater the difference in exercise prices, thus a greater volatility in the option.

The study explores both the Binomial lattice and Black–Scholes (BS) option pricing models. The BS option pricing model is used as the preferred method of ROA in the study.

1.4.2 The Importance of Real Options

As opposed to conventional DCF analysis where a single investment path is predicted with fixed outcomes and all variables are predefined. A ROA reflects numerous investment paths which are an outcome of high uncertainty and managerial flexibility. This type of capital budgeting allows for better alignment with business strategies as investment value is actively adapted to newly available information. According to Mun (2006, pg. 92)

> *Traditional approaches assume a static decision-making ability, while real options assume a dynamic series of future decisions where management has the flexibility to adapt given changes in the business environment.*

1.5 Combining Real Options and Discounted Cash Flow

This study bridges the gap between higher mathematics associated with Real Options Analysis (ROA) and conventional Discounted Cash Flow (DCF). The study investigates the addition of ROA to supplement the traditional DCF capital budgeting of physical assets. Instead of looking only at the differences between the two approaches, the framework exploits commonalities. Identifying differences between the two methods adds extra insight to the analysis, but exploiting mutual bonds is key in making the framework familiar, compatible and understandable.

A basic illustration reveals that although DCF analysis techniques lack depth in valuing uncertainty and managerial flexibility, they are the most commonly employed capital budgeting techniques used in industry. ROA is sparsely implemented yet the structure surrounding it can provide far better insight into investment value and capital budgeting decisions. It is far more adjustable to business realities and adapts timely to new circumstances and information. By implementing a *combined* ROA and DCF capital budgeting technique, real options analysis can be based on everyday DCF variables. This will support an easier transition from DCF to ROA without repressing everyday processes and at the same time, improve conventional capital budgeting decisions by using some form of ROA.

1.6 Problem Statement

Behind every major investment decision there should be some calculation of what that investment is worth. The evaluation of these investment decisions is a key driver in a company's overall performance. Today the most common calculation used by financial specialists and managers to evaluate the return on investments are Discounted Cash Flow (DCF) techniques. According to Baker *et al.* (2011) however, DCF analysis does not take into account the realistic valuation of an investment as it fails to overtly account for the value of real options that are innate in capital budgeting. In fact DCF techniques do not provide sound valuation in an uncertain environment, and company's lose the value created through flexible decision making.

The study aims to address deficiencies associated with DCF analysis by supplementing capital budgeting analysis with ROA techniques. The topic of real options initially created an interest with authors such as Luehrman (1998*a*) who liken physical asset investments to the exercising of real options. Real options are derived from stock market option valuation, however they are applied to real, tangible assets; hence the term "real options". The reference to physical, tangible real options quite naturally then led to its use in a PAM framework, such as PAS 55. According to PAS (2008) physical assets are defined as plant, machinery, property, vehicles, buildings and any other items which carry distinct value.

This study explores the added value in investment opportunities by implementing ROA in the capital budgeting of physical assets. Real options provide a framework for decision making under uncertainty explains Steffens and Douglas (2007), where an investments value is enhanced by the flexibility of future options. As clarified by Ford *et al.* (2004, p. 2) "*options are strategies that include a right, without an obligation, to take specific actions in the future, at some cost, and contingent on how conditions, initially uncertain, evolve.*"

The following shortcomings were identified in DCF capital budgeting assumptions and techniques:

i) Decisions are made now and cash flow streams are fixed for the future.

ii) Future cash flows are highly predictable and deterministic.

iii) Once started, projects are passively managed.

iv) All risks are accounted for by the discount rate.

v) All factors affecting the outcome and value of the project are reflected by DCF techniques such as NPV and IRR.

This study aspires to create a framework that can address the problems associated with conventional DCF capital budgeting techniques within a Physical Asset Management (PAM) structure. This objective is achieved through the following means:

i) *The implementation of a combined Discounted Cash Flow (*DCF) *and Real Options Analysis (*ROA) *capital budgeting tool.*
The combined capital budgeting tool implements real options analysis principles based on widely used DCF techniques. Due to the widespread use of DCF techniques, the relevant information is easy to collect and relate to real option parameters. By using option pricing valuation methods such as Black-Scholes, the real option value inherent in physical assets can be estimated. Real options account for value found in both uncertainty and managerial flexibility. By combining both real option and DCF investment valuations, a more realistic capital budgeting assessment is made.

ii) *The use of an active mapping investment tool based on the above mentioned combined capital budgeting framework.*
Using the metrics established in the combined ROA and DCF analysis, the investments can be plotted on an active mapping framework. The active mapping tool plots the investment according to two axis, with one axis being a risk metric and the other a value-to-cost metric. The active map uses the same information generated in the combined framework yet has the added benefit of visually presenting the investment path through active decisional criteria. In addition, scenario analysis are generated to further visually illustrate various investment pathways and actively include management in making more informed decisions.

iii) *By validation.*
The framework developed will be implemented in a relevant physical asset investment capital budgeting case study within an organisation accustomed to Physical Asset Management (PAM).

Having outlined the central research problem as well as the key objectives of the study, the main research questions is now defined:

> **Research Question:** *Can a combined ROA and DCF visual mapping investment tool supplement conventional capital budgeting techniques within a PAM framework?*

Based on the research question, following from both the outlined problem statement and research objectives, the study aims to disprove the following null hypothesis.

> **Hypothesis:** *A combined ROA and DCF visual mapping framework cannot be used to supplement the capital budgeting of investments within a PAM framework.*

1.7 Research Design: Mixed Methods

What is Mixed Methods?

According to Creswell and Clark (2007, p.5) mixed methods research can be defined as follows :

> *Mixed methods research is a research design with philosophical assumptions as well as methods of inquiry. As a methodology, it involves philosophical assumptions that guide the direction of the collection and analysis and the mixture of qualitative and quantitative approaches in many phases of the research process. As a method, it focuses on collecting, analysing and mixing both quantitative and qualitative data in a single study or series of studies. Its central premise is that the use of quantitative and qualitative approaches, in combination, provides a better understanding of research problems than either approach alone.*

Mixed methods research combines both qualitative an quantitative studies to strengthen weaknesses in both cases. In many cases it is argued by Creswell (2009) that qualitative research has been seen as weak in circumstances where personal interpretation is made, often resulting in bias and generalising of qualitative findings. Quantitative research however, does not have these attributes, it does however have other disadvantages which are combated through qualitative means. Quantitative studies can often lack in contextual setting or background says Creswell and Clark (2007), and often personal bias and interpretations are not discussed. This again is where qualitative research can aid in quantitative studies, making a full circle, mixed methods can strengthen arguments through the use of both qualitative and quantitative reasoning.

The mixed methods design is explained in further detail in the Chapter outline to follow combined with Figure 1.3. The mixed methods study design is used in this study to explore the use of an active mapping framework (Chapter three) developed for the capital budgeting of physical assets. The mixed methods design suggests building up an argument through qualitative means (literature study) and then implementing the framework quantitatively (case study) to evaluate and verify the developed framework.

1.8 Thesis Outline

This section provides a brief breakdown of each chapter, giving limited insight into structure and content of each chapter. In the hopes of providing further insight, Figure 1.3 has been provided to illustrate the alignment between each chapter and the *mixed methods* research design implemented. By starting with the literature study, a foundational qualitative structure is secured based on in-depth literature on topics extending from discounted cash flow to real options. Using the literature, Chapter 3 introduces an active option mapping tool to be implemented in the next phase. The quantitative phase validates the framework presented in Chapter 3 as it executes the active mapping tool through a case study in Chapter 4. Mixed methods aim to strengthen research arguments by combining both qualitative and quantitative findings, this is done in Chapter 4.

Chapter 2: Literature Study

The literature study consists of three primary foundational structures namely: Physical Asset Management (PAM), Discounted Cash Flow (DCF) and Real Options Analysis (ROA). Qualitative structures are used to create the contextual framework of a *combined* discounted cash flow and real options framework. The framework will be implemented in aiding the capital budgeting of physical assets within a PAM structure using a standard such as PAS 55. The literat-

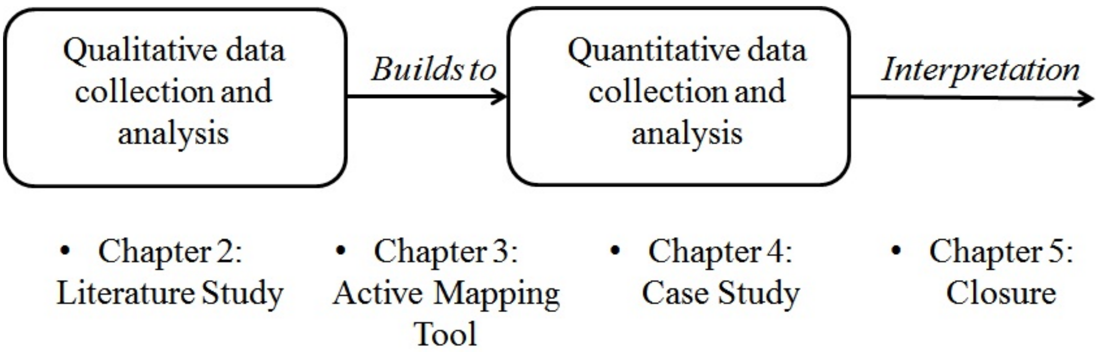

Figure 1.3: Chapter overview aligned with exploratory sequential research design

ure outlines widespread DCF techniques such as NPV, along with advantages, disadvantages and key deficiencies in DCF valuation criteria. The argument continues leading into the background, theory and real world applications of real option analysis and the option valuation of real or physical assets.

Chapter 3: Building an Active Mapping Investment Tool within a Physical Asset Management Framework

Chapter 3 describes the framework of a combined active mapping tool which will be validated quantitatively in Chapter 4. Chapter 3 investigates the use of supplementary real options analysis techniques in the valuation of investments currently using conventional DCF analysis. The supplementary real options analysis consists of two primary tools, the first is an option valuation equation known as Black–Scholes. The second is an interactive and visual active mapping framework, which combines both conventional DCF information as well as real option information from a replicating portfolio. The active mapping tool gives a visual indication of the investment along with a scenario simulation, while the Black–Scholes equation gives an appreciation of the option value attached to the physical asset investment.

Chapter 4: Case Study

The case study done through Anglo Platinum investigates the implementation of the combined active mapping framework outlined in Chapter 3 by using an industry relevant investment example. The case study investigates two major physical assets which are used in the transportation of raw materials from mining operations to production facilities. The investments are mutually exclusive and the case study evaluates the capital budgeting investment potential of either building a new road or an overland conveyor to transport raw materials. Chapter 4 outlines the background of the study, variables as well as relevant assumptions. The case study is presented in hopes of validating the active mapping framework outlined in Chapter 3.

Chapter 5: Closure

The final chapter presents an abridged overview of the content of the study before moving onto the limitations encountered within the study. Based on the limitations outlined along with additional insight into the research field some recommendations are noted for future research. In closing, the final conclusion is put forward, aligning with the study objectives and hypothesis drawn.

Chapter 2

Literature Study

The literature study presents three core topics which are used in the formulation of the research argument for this study. The three core topics are Physical Asset Management (PAM), Discounted Cash Flow (DCF) and Real Options Analysis (ROA). The primary aim is to combine DCF and ROA and create a combined decisional tool in the capital budgeting of investments in a PAM framework.

2.1 Physical Asset Management

The aim of this section is to provide a comprehensive summary of physical asset management. *Physical assets* are defined as plant, machinery, property, buildings, vehicles and other items that have a distinct value to an organisation. *Physical asset management* is the way in which these items of distinct value are cared for from acquisition, through their life cycle until they are disposed of.

2.1.1 The Evolution of Asset Management

It is thought by Woodhouse (2003) that the initial movement towards asset management began in the late 1980's within the oil industry. Numerous issues and events within the industry necessitated a radical shift from the contemporary business models. A pivotal finding was that although larger companies secured strategic advantage with their large economies of scale, they lacked an integrated thinking approach which many smaller businesses naturally enjoyed. Within this new integrated thinking process began the slow planning of an asset-centred business approach.

Until recently there have been two dominant definitions describing the management of assets, as stated by Amadi-Echendu *et al.* (2011). The first relates to the information and communication technology needed to manage data relating to assets, while the second focused on integrating asset management areas to enable more informed decisions about a portfolio of assets. More recently however the focus has been on *total* asset management which looks at the overall dimensions of what constitutes engineering asset management. One such example is Madu (2000) who believes maintenance, reliability and cross-organisation are key elements in managing equipment asset use, it is argued that asset management should be facilitated by the use of IT (Information Technology) software.

Given that the definition of "assets" encompasses a large array of items it is only natural that asset management has been defined in a variety of different contexts, such as transport by McElroy (1999), construction by Vanier *et al.* (2001), electricity by Morton (1999), chemical engineering by Chopey and Fisher-Rosemount (1999) and even irrigation by Malano *et al.* (1999).

In outlining asset management within the U.S. transport industry McElroy (1999) defines asset management as a "*systematic process of maintaining, operating and upgrading physical assets cost-effectively.*" It is argued that effective asset management needs an asset based decision making framework that can incorporate organisational structure and IT aligned with financial and budgetary factors. These views are in contrast to Malano *et al.* (1999) who believed in key principles which should apply to asset management. Principles which consist of pre-asset acquisition strategies for planning and initiating assets, asset operation and maintenance, performance monitoring, together with asset accounting and economics, audit and renewal analysis. Vanier *et al.* (2001) found the life cycle analysis of assets more important, stating that in infrastructure and practice there is a growing interest in moving asset management towards new horizons, away from traditional forms such as maintenance.

As theories evolved, becoming more complex and customised, it became evident that more factors are presented. Authors such as Tsang (2002) have recognised the effects of human decisions in the effectiveness of asset management and its overall success. In addition to this Woodhouse (2001) describes the asset manager as the link between business objectives and engineering, ultimately affecting economic outcomes from physical assets in an ever changing environment of technology, ideas, regulation and social dynamics. According to Woodhouse (2001, adapted by Amadi-Echendu *et al.* (2011)) the greatest threat to effective asset management is humans and the lack of educated decision makers with the ability to adapt to its sophisticated needs. It is believed that many of the techniques and know-how already exist, they need only be adapted to produce more effective means of asset management. It is the human factor that is the weak link in the chain.

The contrast in asset management structures, principles and practices previously reflected upon are clearly disjointed and unstructured if put into practice. This however, does not mean it is less important, in fact quite the opposite applies. Clearly what is needed is an industry standard which can be used as a model for various organisations specialising in a variety of asset classes. This is exactly what the Institute of Asset Management (IAM) and British Standards Institution (BSI) have created in the form of Public Available Specification 55 (PAS 55). It is an industry standard, specifically for asset management. It defines common terminology and specifies the requirements for the optimised management of physical assets. The section to follow outlines the PAS 55 framework and highlights key areas which are specifically addressed in this study.

2.1.2 Public Available Specification 55

Public Available Specification 55 (PAS 55) was first introduced in 2004 with the collaboration between the Institute of Asset Management (IAM), the British Standards Institution (BSI) and a number of co-operating organisations and individuals. It is applicable to organisations where physical assets are fundamental in accomplishing business objectives. In accordance with PAM, the PAS 55 framework provides key objectives and requirements to facilitate the integration of PAM with a wide range of related management systems and various different asset classes. According to a PAS (2008, pg. v) PAM is defined as:

> *the systematic and coordinated activities and practices through which an organization optimally and sustainably manages its assets and asset systems, their associated performance, risks and expenditures over their life cycles for the purpose of achieving its organizational strategic plan*

In successfully implementing a fully integrated PAM framework, PAS 55 combines four other broad based asset categories to fully align an organisations asset management with business goals and strategic planning. The other four asset classes are human assets, information assets, financial assets and intangible assets. Figure 2.1 below illustrates the relation of physical assets within the other four asset classes as well as the scope of PAS 55. It demonstrates critical interdependencies that form the scope of PAS 55 and their relationship with other asset classes. Although human factors such as culture, leadership and motivation are not directly dealt with in PAS 55, they are essential in achieving optimal and sustainable asset management, and do need attention.

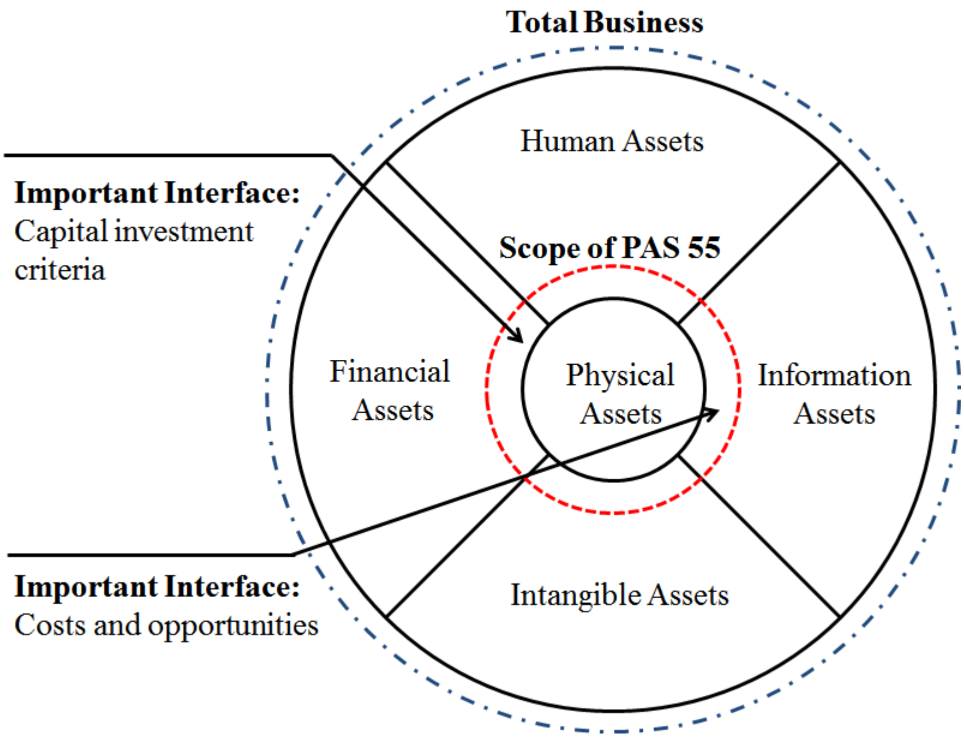

Figure 2.1: Research focus areas in relation to PAS 55 asset categories

Adapted from PAS (2008)

Figure 2.1 illustrates the importance of the *Financial Assets* in relation to not only the *Physical Assets* but also to *Total Business*. The key aspects highlighted in the interface between financial assets and physical assets is the *capital investment criteria*. In addition to this, the interface between information assets and physical assets focuses on *costs and opportunities*. The investigation of this study deals directly with these two interfaces. More specifically the study investigates the implementation of more effective capital budgeting techniques in the acquisition of physical assets.

Within PAS 55 are various levels at which assets can be identified and managed, this can vary from discrete equipment to very complex functional systems, networks, sites and diverse portfolios. The hierarchy of these elements, as shown in Figure 2.2, brings a host of challenges and opportunities at different functional levels. One such element is on the foundational level in Figure 2.2, the "create/acquire" triangle on the bottom left. It is within this area of asset creation and acquisition that a capital budgeting approach is implemented in aiding investment decisions and providing more information.

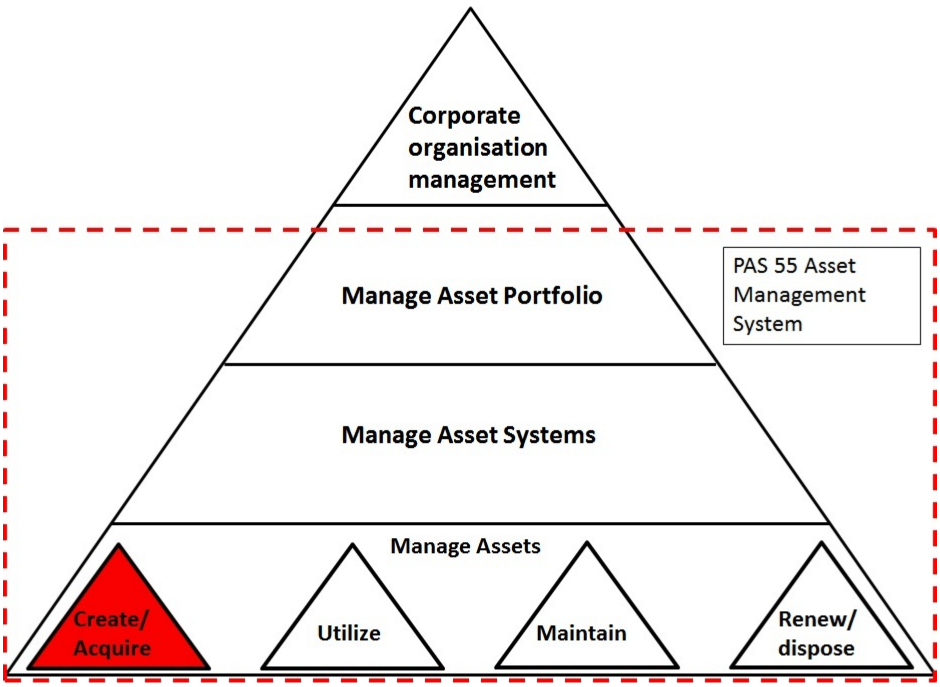

Figure 2.2: Asset management levels: Focus area

Adapted from PAS (2008)

By using PAS 55 as a foundation, the study presented uses real option valuations in the initial step of life cycle activities. More specifically the *acquire/create* step within the management activities as shown in Figure 2.3. Now that the foundational topic has been established, the next two chapters presented aim to give just reason to the implementation of a supplementary real options framework to the widely used DCF methods currently employed in the investment of physical assets.

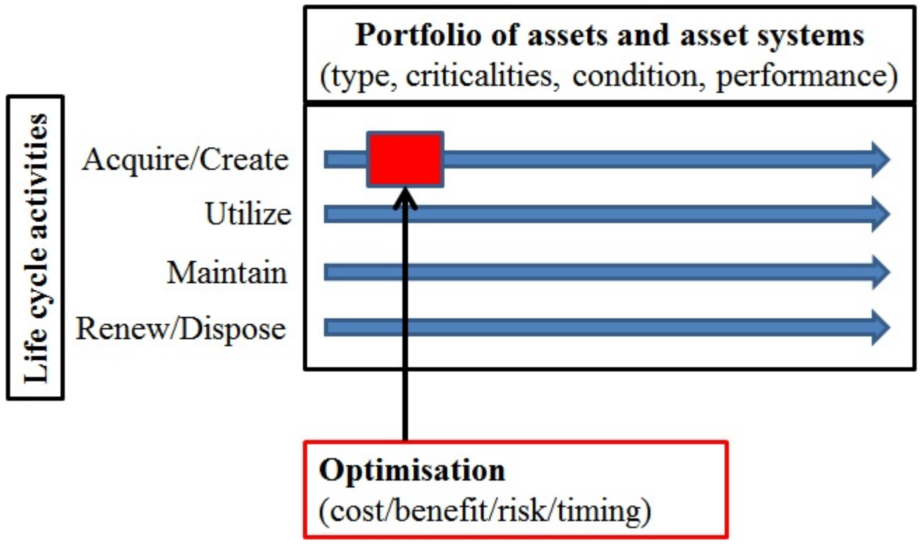

Figure 2.3: Primary requirements for optimisation of asset management activities

Adapted from PAS (2008)

2.2 Capital Budgeting

According to Bierman and Smidt (2006) corporate managers must decide on the direction of their organisations based on strategic capital budgeting decisions. Time is an important element of capital budgeting decisions. Fundamentally, most capital budgets are set in the future meaning corporate directors have to deal with the uncertainty of future forecasting. In many cases, resources are allocated and investment decisions are made with little knowledge of the consequences. Any effective capital budgeting plan takes into account four basic factors:

i) Present value

ii) The time value of money

iii) Risk and return

iv) Asset class

These concepts have been clarified in the Introduction, specifically outlining the importance of concepts such as time value of money, discount rates and the concept of company specific risk and return. In considering these concepts three basic generalisations that are most prevalent in investment decisions can be deduced. The first is that investors will always prefer a higher more profitable return. The second is that investors would always prefer to have as little risk associated with their investment as possible. Risk however is relative as often higher risk presents higher rewards. The third and final generalisation is that money received today is worth more than the same amount of money received in the future. This is due to the decreasing time value of money as well as the possible returns which can be earned on money invested.

Investment type

There are various classifications of investments, project risks and the priority of investments. They are determined according to the profile classified and in this section, the investment type. Projects may be classified in a number of ways:

i) Replacement or expansion projects

ii) Independent or mutually exclusive projects

iii) Divisible and indivisible projects

The fist investment type discussed are replacement and expansion type projects. The *replacement* investment type refers to the acquiring of assets in efforts to maintain production levels. Reasons for replacement are usually to increase efficiencies within the production line, often resulting in operating cost reduction. The *expansion* of projects usually occurs in two main areas. The first is new product expansions, where organisations explore new investment possibilities and thus must acquire new and relevant assets. The second expansion phase relates to an increase in current production, which could be as a result of introducing current products into new markets explains Correia and Wormald (2011).

The second investment type is independent or mutually exclusive projects. Consider two projects *project 1* (P1) and *project 2* (P2). The two projects are considered independent if P1 can be accepted or rejected, regardless of the condition of P2. Mutually exclusive projects are more difficult to consider as only one of the investments can be chosen (given funding constraints), thus only P1 or only P2 can be chosen. Lastly is the topic of either divisible or indivisible projects. A *divisible* project can be broken up into a series of parts, each of which can be completed independently. An indivisible project, cannot be split up and the entire project must be undertaken.

2.2.1 Capital Budgeting Techniques

Capital budgeting is the planning process used to determine whether an organisations investments are worth pursuing. Central to the capital budgeting valuation procedure is the process of Discounted Cash Flow (DCF) analysis. DCF analysis uses the concept of *time value of money* to evaluate a projects profitability. In employing the Present Value (PV) concept and using a discount rate future cash flows are discounted to reflect the PV according to varying time spans. Equation 2.1 below illustrates how future cash flows are discounted to a PV using DCF analysis.

$$\text{DCF} = \frac{CF_1}{(1+r)^1} + \frac{CF_2}{(1+r)^2} + ... + \frac{CF_n}{(1+r)^n} \tag{2.1}$$

Where, r = discount rate, CF = cash flow and n = maximum time period.

The equation illustrates how the cash flows (CF) are discounted using the discount rate specified (r). This is done periodically by using the time period (t) and by inspection it can be seen that values forecast further in the future are discounted more severely due to the increasing denominator. Listed below are a number of formal methods commonly used in the capital budgeting of investments:

i) Accounting Rate of Return (ARR)

ii) Payback Period (PB)

iii) Net Present Value (NPV)

iv) Internal Rate of Return (IRR)

v) Real Options Analysis (ROA)

In terms of the valuation techniques listed above, all except the Payback Period (PB) and Accounting Rate of Return (ARR) use DCF techniques. The capital budgeting techniques such as DCF and IRR will be explained in more detail in the next section. The Real Options Analysis (ROA) techniques are based on financial option theory and is also only reflected upon in subsequent sections. This section serves to illustrate the use of non discounted cash flow capital budgeting measures such as the PB method.

Example: Payback Period Method

The Payback Period (PB) method evaluates the time it takes for an investor to salvage the cost of the investment from the future cash flows generated. It is a rough risk estimate as it calculates how long the cash flows are at risk for. It does not take the time value of money into account by discounting the future cash flows. Consider Table 2.1 below where two investments A and B are compared using the PB method.

Table 2.1: Comparing two investments: Payback Period (PB)

	Cash Flows (Rm)				
Year	0	1	2	3	4
Investment A	-15	6	7	8	10
Investment B	-15	4	5	6	7

From Table 2.1, the investment costs can be seen in year 0 as -R15 million. For Investment A the PB is 3.25 $(3 + 2/8)$ years and Investment B has a PB of 3.85 $(3 + 6/7)$ years. Thus Investment B is seen as a higher risk due to the longer period cash flows take to pay off the investment. The best investment is Investment A. The payback method is very simple to use, but neglects any significant risk calculations, although it does have its place in capital budgeting, it is generally used as a quick estimate and seldom used alone.

2.2.2 The Weighted Average Cost of Capital

The cost of capital[1] is used to estimate the PV of cash flows by using the understanding of the *time value of money*. Over time, there have been many questions surrounding the use of an appropriate discount rate. Surveys carried out on firms by Gitman and Mercurio (1982), Petty *et al.* (1975) and Schall *et al.* (1978) indicated that at least three quarters used one discount rate in capital budgeting. One such commonly used discount rate is the Weighted Average Cost of Capital (WACC). Slow to catch on in industry at first with only 30% of companies adopting the principle explains Williams Jr (1970) and Petty *et al.* (1975) the number of firms applying the WACC in discounting increased to around 45% by 1978. By the late 1990's WACC had become fully integrated into capital budgeting techniques with 93% actively using WACC as supported by Bruner *et al.* (1998).

In most cases there are two primary assumptions which must be adopted in the calculation of the cost of capital.

i) A targeted capital structure: This implies that the organisation acknowledges that there is sufficient equity and debt to finance the organisation.

[1]Cost of capital is also known as the *discount rate* and the *hurdle rate*

ii) Similar risk assumption: It is assumed that the organisation will use one overall rate of return. In doing this it assumes all asset investments acquired fall under the same risk profile.

Thus WACC refers to the rate of return expected by the providers of capital given a firms particular risk levels. The WACC incorporates all risks associated with the funds required to finance the asset based investments. According to Correia and Wormald (2011) the following elements illustrate why it is important to use WACC:

i) The evaluation of capital projects: An important evaluation tool in assessing if the projects return exceeds that of the company's cost of capital.

ii) The valuation of organisations: The WACC is the principle discount rate used in DCF valuations.

iii) Determining Economic Value Added (EVA): Organisations are increasingly making use of Economic Value Added (EVA) to measure financial performance. The EVA metric is based on the company's WACC

$$\text{EVA} = \text{Operating Income} - (\text{WACC} \times \text{Invested Capital})$$

iv) Using WACC to frame pricing decisions: This applies to the determination of industry specific WACC rates. Meaning that a mining industry will have different structures to those in the water or energy industries.

v) Determination of fair value: In many corporate evaluations of assets there is a lack of knowledge on industries valuation of these assets. By using WACC a fair value of the assets can be attained.

The WACC is represented below in Equation 2.2.

$$\text{WACC} = K_{\text{d}}\,(1 - tr)\,(D/V) + K_{\text{e}}\,(E/V) \tag{2.2}$$

Where K_{d} = cost of debt, K_{e} = cost of ordinary equity, tr = marginal company tax rate, D = market value of debt, E = market value of ordinary equity and V = market value of the firm.

2.2.3 Capital Asset Pricing Model

The value of an asset from a capital budgeting perspective is often specified in terms of its rate of return. The return, based on the subject of discount rates and the WACC subjects outlined, should contain some measure of an asset's risk. The Capital Asset Pricing Model (CAPM) endeavours to assess the risk of a financial asset and to convey its value in terms of the required rate of return explains Correia and Wormald (2011). The CAPM embraces the reality of a certain amount of risk present in the market which applies to all capital assets and must be accepted by the investor. Any other risks are seen as atypical to the specific asset and can be mitigated through *diversification*[2]. Thus the only risk that is relevant in the context of a portfolio of assets is atypical risk which cannot be diversified away. The CAPM tries to establish the influence of the *undiversifiable*[3] risk and provide an estimated risk with which investors can decide whether to purchase the investment or not.

$$k_r = r_f + \beta(R_m - r_f) \tag{2.3}$$

Where k_r = the return required by equity holders, β = the beta value of a share and R_m = the return on the market portfolio.

The CAPM is made up of two parts. The first is the risk free rate r_f which is the rate of return expected from an investment in an asset that is deemed "risk free" (such as government bonds). The second part is the market risk premium $(R_m - r_f)$ which is multiplied by the β risk associated with the specific asset invested in to get the asset specific risk premium $\beta(R_m - r_f)$. The risk premium accounts for the additional risk associated with the specific asset: investors will require greater returns for exposure to this increased risk. From the equation it can be seen that if the risk of the investment increases so too does the risk premium. There is a great deal of debate over the CAPM calculation with special attention to the β value and the equity market index.

In a study carried out by Gitman and Vandenberg (2000) of 111 major U.S. firms some alarming findings relating to the CAPM where highlighted.

[2] In finance, diversification means reducing risk by investing in a variety of assets.
[3] Also *non-diversifiable* risk and measured as the β value of an asset(share).

i) 93% of companies use CAPM to estimate their cost of equity.

ii) Nearly all companies use one cost of equity regardless of the financing needed.

iii) Companies tend to use target weightings instead of more accurate market representative book weightings.

iv) The majority of WACC calculations for a discount rate consist of the CAPM model.

Despite these facts, the CAPM remains one of the most widely used measures of equity incorporated in the WACC discount rate calculation. Although openly criticised for its irregularities and unspecified variable definitions, it is used industry wide with little regard of the consequences. Conventional DCF analysis uses one principle discount rate to account for all possible future risks, worse still, this discount rate is often unchanged for various investment proposals.

2.3 Discounted Cash Flow Techniques

2.3.1 Introduction

Capital budgeting techniques have evolved considerably in the past four decades as surveys have outlined. According to Ryan and Ryan (2002) Accounting Rate of Return (ARR) and non-discounted Payback Period (PB) methods were preferred over Net Present Value (NPV) and DCF techniques. Both (DCF and NPV) of which have in this modern day been considered far superior. Some of the earliest studies reporting the use of capital budgeting techniques by Klammer (1972) shows a sample of 184 U.S. firms in 1959 where 34% of firms used PB methods while another 34% preferred ARR methods, leaving as little as 19% using DCF methods. Even in these early days of capital budgeting studies there were many disputes among academics as to which were the most successful methods states Ryan and Ryan (2002). While Miller (1960) and Pike (1996) favoured the PB technique, others such as Istvan (1961) show preference to ARR. Although this carries some significance, by the 1970s researchers, academics and businessmen alike saw far more relevance in DCF techniques.

By 1970, a new revolution had begun with reports of 57% of firms using DCF methods and with ARR dropping to 26% and only 12% relying on PB methods explains Hermes *et al.* (2007). This is not to say that DCF techniques were the only methods of capital budgeting used, more however that the influence of more sophisticated and reliable methods became a valued priority. In a study by Hendricks (1983) it was found that by 1981, 76% of his sampled firms were using DCF methods as their primary budgeting tool, with as little as 11% using PB methods as a primary tool. A radical transformation was cemented by the 1990's, with studies concerning the large Fortune 500 companies by Trahan and Gitman (1995). Studies by Trahan and Gitman (1995) revealed that most companies were using DCF methods as a primary evaluation tool with 88% using NPV and 91% using IRR. In the smaller companies however, DCF methods were still highly prominent, but the figures were far lower with 65% using NPV and 54% relying on IRR. The popularity of DCF methods grew significantly with time, firmly cementing them as the favoured method of capital budgeting. In an extremely thorough survey published by Graham and Harvey (2001) consisting of 392 CFOs from firms in the U.S. and Canada, it was reported that IRR and NPV methods were the most frequently used capital budgeting techniques. The survey announced that 76% of CFO's always/almost always use the IRR method with 75% always using NPV. The use of DCF capital budgeting methods resulted in an increased focus on aspects such as uncertainty, risk and the timing of investment opportunities explains Bierman and Smidt (2006).

2.3.2 Net Present Value

The most widely implemented and reliable DCF method enforced in making investment decisions is the Net Present Value (NPV) method explains Hermes *et al.* (2007). The NPV method accumulates all costs and benefits in an investment decision and estimates which of the two is greater. More specifically, NPV is calculated by discounting the incremental cash flow created by the investment says Del Sol and Ghemawat (1999). With an appropriate discount rate, the DCF analysis accepts an investment should the NPV be greater than zero, as if this is the case, the investment will create value for shareholders. According to Thomas (2001) by using a discount rate, DCF theory presumes that a rand today is worth more than a rand tomorrow, and that a certain rand is worth more than a risky rand.

The calculation of the NPV is demonstrated by Equation 2.4 below. By discounting the future cash flows to the present value using the prescribed discount rate and subtracting the investment cost, the NPV is calculated. Should the NPV be positive, value is added and the decision to invest should be taken. If the NPV is negative, the investment destroys value and thus the investment should not be undertaken.

$$NPV = \sum_{t=1}^{n} \frac{CF_{\mathrm{t}}}{(1+r)^{t}} - X \tag{2.4}$$

Where, X = cost of the investment, t = time period, CF_{t} = cash flows at time t and n = number of time periods.

Example: Capital budgeting using NPV

An example NPV calculation is presented with the aid of Table 2.2. The table provides two periods starting with the acquiring of a physical asset in year zero. The price of the asset is R12 337 and the organisation acquiring the asset expects R10 000 in cash flow in year one and R5 000 in year two. The organisation has adopted a discount rate r of 10%. The organisation is using an NPV capital budgeting technique to evaluate the investment.

Table 2.2: Computation of NPV using 10% discount rate

Period	Cash flow	Present value factor	Present value
0	-$12 337	1	-R12 337
1	R10 000	0.9091	R9 091
2	R5 000	0.8264	R4 132
		Net Present Value =	R886

$$\begin{aligned} NPV &= -12\,337 + 10\,000(1+r)^{-1} + 5\,000(1+r)^{-2} \\ &= -12\,337 + 9\,091 + 4\,132 \\ &= \text{R}886 \end{aligned} \tag{2.5}$$

By using Equation 2.4 and applying the variables outlined in the example, the investment NPV is expressed in Equation 2.5. The positive result of R886 means that acquiring the asset will add value to the organisation and thus the decision to accept the investment should be taken.

DCF has established itself within the last 40 years as firms have increased the use of DCF models to support investment decisions. According to Klammer and Walker (1984), where figures have been extrapolated from surveys found in literature, it has been concluded that nearly all large U.S. firms still use DCF methods in some investment decisions. Lending to the fact that DCF methods are still both beneficial and consistent. Furthermore in an empirical study by Kaplan and Ruback (1995), NPV is confirmed as an appropriate and reliable decision criterion, as it provides estimates consistent with market values. More specifically, the study shows how 51 highly leveraged sampled values were within 10% to the equivalent NPV projection. A supplementary list of advantages is also provided by Thomas (2001, p. 17) highlighting key advantages of DCF analysis over other alternative methods.

i) Clear, consistent, decision criteria for all projects.

ii) The same results, regardless of risk preference of investors.

iii) Quantitative, precise, and economically rational results.

iv) Less vulnerability to accounting conventions (depreciation, etc).

v) A way of factoring in both risk and the time value of money.

vi) A process that is relatively simple, widely taught, widely accepted.

DCF analysis is a great investment decision tool, as long as the investment decisions fit the assumptions of the analysis. Above all, DCF analysis has the advantage of simplicity as it reduces a project or capital investment into a single figure, with one criteria in making a decision (NPV $>$ 0) continues Thomas (2001).

2.3.3 Internal Rate of Return

Another method associated with discounted cash flow is the Internal Rate of Return (IRR). The IRR is the calculation of the discount rate which will cause the NPV to equal the investment cost. This ultimately reflects the rate of return of the project in percentage terms. This rate of return percentage is then compared to the actual discount rate for the investment and if the return rate is higher, then the investment is accepted. The formula is expressed in Equation 2.6 below. The difficulty with the equation is that r, the unknown variable, which needs to make the NPV equal zero is found iteratively through trial and error. This normally causes difficulty compared to NPV, however financial calculators and Excel are used in practice. It has been accepted, however, that the NPV approach renders more credible results states Brealey (1991, chapter 5).

$$\sum_{t=1}^{n} \frac{CF_t}{(1+r)^t} - X = 0 \tag{2.6}$$

In summing up the most widely implemented capital budgeting techniques Table 2.3 is provided. The supplementary table presents a brief description along with brief advantages and disadvantages associated with each method.

2.4 Shortcomings and Deficiencies of Discounted Cash Flows

Although financial theory supports DCF techniques in assessing the viability of capital budgeting projects and investments, DCF techniques do have limitations. Authors such as Trigeorgis (1988, 1993) and Van Putten and MacMillan (2004), among others, suggest that traditional DCF methods do not account for decisional flexibility in the capital budgeting of projects. DCF

Table 2.3: Capital budgeting technique descriptions

Method	Description	Advantages	Disadvantages
Net Present Value (NPV)	Discounts the expected cash inflows from a proposed project at the required rate of return(or hurdle rate). Projects that have a positive NPV are said to "add value" to the firm and are considered acceptable. The greater the NPV, the more value added to the firm by accepting the project.	Does the best job of simultaneously determining the acceptability of a project and the ability to rank order projects by the amount of wealth added to the firm by each.	May not be optimal in the periods of capital rationing, as consideration of project size relative to NPV requires additional analysis.
Internal Rate of Return (IRR)	Determines the rate of return generated by a project. IRR is the rate that equates the present value of cash inflows with the present value of cash outflows. The greater the IRR, the greater the rate generated by a project.	Easy to understand an communicate and gives similar accept/reject decisions as NPV	Multiple IRRs are possible with some projects and may not result in selection of optimal projects under mutually exclusive conditions.
Payback Method	Determines howlong it will take to earn back the initial costs of a project.	Easy to understand and calculate and with altered forms, can include time value concepts.	Ignores cash flows beyond the payback period, thus biasing it against long-term projects. May not always accept projects that have value to the firm.
Accounting Rate of Return	Determines the amount of accounting profit per unit of book value	Easy to calculate with information easily available	Time value of money is ignored and based on accounting values (not cash flows), which may be arbitrary.

Source: (Filbeck and Lee, 2000)

analysis does not take into account the realistic valuation of an investment as it fails to overtly account for the value of real options that are innate in capital budgeting explains Baker *et al.* (2011). In fact DCF techniques do not provide sound valuation in an uncertain environment, and firms lose the value created through flexible decision making. Authors such as Tiwana *et al.* (2007) are concerned with the lack of structured information which managers use in the pursuit of assessing the value of certain project opportunities; this often leads to considerable ambiguity in decision making.

Apart from the a broad base of advantages, DCF methods appear to fall short in a number of significant aspects. Some of the initial limitations associated with DCF frameworks are the irregular use of methods; a failure to enumerate certain factors such as; inability to account for option values and the incapacity to account for competition. The first drawback listed is the irregular use of DCF methods which can be divided up into an assortment of various forms. Some of the misuses of DCF methods includes discounting real flows with nominal interest rates, failing to correctly implement inflation; applying unnecessary risk-adjustment factors, a lack of recognising that diversification of risk should not be considered; using unsuitable criteria in measuring profitability, such as IRR, which often bear erroneous conclusions; using standardized accounting principles which reflect incorrectly on determining cash flows; also often gauging investments separately which are related, thus missing investments which compliment one another.

The second set of limitations and shortcomings associated with DCF methods stem from the difficulty in quantifying all costs and advantages. As investments vary, so too does their quantifiable value, which is an extremely flexible decision and not simply measured. Take for example the difference in ease of value quantification between a piece of equipment which is to be replaced; and the training of employees. The latter is far more difficult to estimate in value, and often under or over valued. Unfortunately in a DCF framework, sophisticated formulas and simulations are not recommended and thus limit the valuation of costs and advantages provided by common DCF analysis.

The third disadvantage of DCF methods is its lack of flexibility in including option valuation and forecasting investments to incorporate some uncertainty.

Although this problem has been recognised, some authors such as Luehrman (1998*a*) have incorporated real option evaluations using existing DCF models. A forth pitfall in DCF evaluation is the lack of competitive interaction. According to Bierman (1988, p. 3) the lack of more strategic interactions are one of the greatest problems found in conventional capital-budgeting approaches such as DCF. Of all the limitations of DCF methods it is found that the incorporation of competition is of the most valuable. "*The failure to incorporate competition is the most serious drawback*" explains Del Sol and Ghemawat (1999, p. 45).

Besides being favourable and widely used, traditional DCF methods such as NPV lack the ability to actively evolve as a project or a projects management criteria changes. In the case where an investment is evaluated, NPV must be greater than zero. According to Dixit and Pindyck (1995) the NPV evaluation only provides management with basic "accept" or "do-not-accept" decision suggestions. With such limited decision criteria and simplistic implementation NPV is popular, however, it still does not account for any future strategic option value. Dixit and Pindyck (1995) are interested in a real options approach which provides sets of options as opportunities or rights but not obligations, thus a greater freedom of choice. Option rights provide management with flexibility, thus options have a value linked with them. Santos (1991) finds that traditional valuation techniques are not suited for accounting or for management flexibility. In particular NPV disregards a host of future options available for a project, especially when reflecting on a capital investment decision; such as an option to expand, option to delay and and option to abandon should market conditions be pessimistic.

Also of interest is the effect time has not only on the uncertainty of a capital budgeting forecast, but with the timing of relevant information. In a fixed NPV forecast, little can be done to allow for untimely information. Mun (2006) outlines a process of valuing an investment over shorter or longer time periods as shown in Figure 2.4 below. According to Mun (2006), traditional capital budgeting techniques are best suited for shorter time periods that are to some degree deterministic. In a longer time period, more strategic opportunities present themselves and more advanced valuation techniques such as *real* options should be used. The simple reason is that the longer the term of prediction the more uncertain future conditions become, thus the need for more variables, management and flexibility. In an estimate by Mun (2006), DCF analysis should combine historical data and project budget data for the following year, using no more than five years of projected cash flow. New investment techniques however should be used from that point onwards (beyond the fifth year) as demonstrated by Figure 2.4 below.

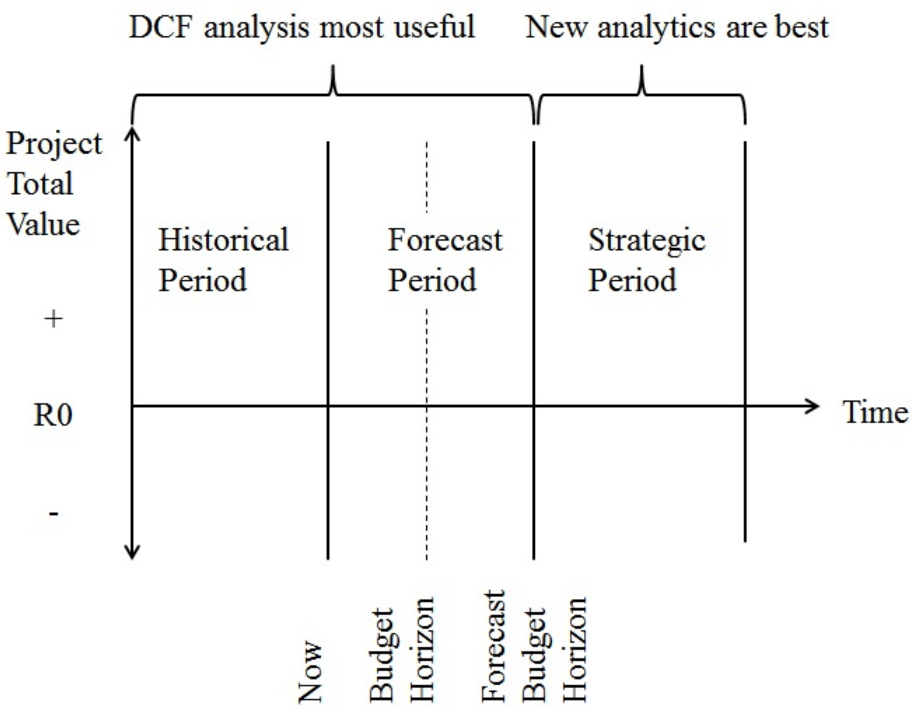

Figure 2.4: Traditional versus new analytics

Based on Mun (2006)

Having assessed a series of DCF limitations, Table 2.4 provides a list of primary assumptions associated with DCF techniques which hinder the significance of its use in reality. The next section introduces further areas where possible shortcomings exist. This outlines the deficiencies in the calculations of discount rates as well as outlines further DCF capital budgeting techniques implemented in industry.

Table 2.4: Disadvantages of DCF: Assumptions versus Realities

DCF Assumptions	Realities
Decisions are made now, and cash flow streams are fixed for the future	Uncertainty and variability in future outcomes. Not all decisions are made to day, as some may be deferred to the future when uncertainty becomes resolved.
Investments are stand-alone and they are interchangeable with whole projects	With diversification and interdependencies, investments are part of a portfolio of other projects and their resulting cash flows. Projects and investments cannot always be evaluated as stand-alone.
Once started, projects are passively managed	Projects are usually actively managed through project life cycle, checkpoints, decisional options, budget constraints etc.
Future cash flow streams are highly predictable and deterministic	It may be difficult to estimate future cash flows as they are usually erratic and risky.
Project discount rate used is based on the cost of capital, which looks at the opportunistic side of nondiversifiable risk.	There are multiple sources of business risks with varying features and some can be diversified over time.
All risks are accounted for by the discount rate	Firm and project risk can vary over the projects development.
All factors affecting the outcome of the project, and the value to investors is reflected in the DCF techniques such as NPV and IRR.	Due to the complexity of projects as well as external factors, it is close to impossible to quantify all factors from cash flows.
Unknown, intangible factors are valued at zero.	Many important benefits are intangible assets or qualitative strategic positions.

Adapted from Mun (2006).

2.4.1 Discount Rates

In conventional DCF analysis, the discount rate is used to hedge the organisation against future risks by discounting future cash flows to a present value. There are two fundamental DCF assumptions with regard to the discount rate which are both flawed and naive in a real business environment:

i) All risks are completely accounted for by the discount rate.

ii) Project discount rate calculated is the opportunity cost of capital, which is proportional to the nondiversifiable risk.

The discount rate is primarily calculated from the Weighted Average Cost of Capital (WACC) and in terms of real, physical assets the nondiversifiable risk value is calculated using the Capital Asset Pricing Model (CAPM) model. As a result of using just one discount rate to account for all future risk and uncertainty, the NPV becomes highly sensitive to the WACC and the present value of the asset is dramatically influenced. Organisations predominantly employ one discount rate for all types of projects and asset based investment decisions. This is a poor representation of risk as various asset classes and investments will reflect different market related volatilities, this results in both an under and over valuation of future cash flows. Worse still, to account for unknown risks, organisations often use a hurdle rate above the WACC, significantly under valuing investments.

By dissecting both the WACC and CAPM equations, key deficiencies and inaccuracies can be seen.

$$\mathrm{WACC} = K_{\mathrm{d}}\,(1 - tr)\,(D/V) + K_{\mathrm{e}}\,(E/V) \tag{2.7}$$

The WACC rate assumes a constant tax rate tr, this is problematic as it is calculated after company tax but before any personal income tax. Investors will have varying tax rates according to personal income, this can result in an overestimation of tax in the capital budgeting of investments. More importantly however, is the asset based beta risk factor represented by the CAPM model. The CAPM model is the most widely implemented calculation of the WACC's cost of equity or K_{e}. The CAPM model is presented below to better illustrate its limitations.

$$k_r = r_f + \beta(R_m - r_f) \tag{2.8}$$

The CAPM affirms that an investments expected return is a function of the risk-free rate r_f, the assets β rate and the market risk premium $\beta(R_m - r_f)$. The model provides no guidance on which risk-free rate to implement and over which time period. The most difficult variable to quantify is β, although industry specific variables are provided, the value changes over time and is difficult to quantify. A study by Fernandez (2009) investigating 1 403 finance and economic professors on the equity risk premium used to calculate the required return to equity showed a variance between 4.1% and 10.5%. Interestingly, the variance didn't just change between countries, but even between professors in the same institutions. In addition a projects beta value can be different from the equity market related beta value. In most cases, organisations do not adapt a beta value or risk-free rate and utilise the same variables irrespective of the proposed investment, further hindering the credibility of the WACC discount rate.

In short, there is much debate over the accurate calculation of the WACC discount rate. Despite this evidence though, the WACC is highly used in industries worldwide and frequently implements the risk factored CAPM model. There are many inconsistencies related to both models and the overall calculation of the discount rate. This is problematic in the valuation of investments, primarily through undervaluation as organisations overcompensate risk factors in discounting future cash flows. Beside these facts however, those in practice are largely immune to criticism as few alternatives are present. This study provides further insight into the valuation of risk through the use of investment specific volatility measures combined with Real Options Analysis (ROA). ROA accounts for value found in risk and uncertainty that is generally frowned upon in conventional DCF analysis. The next section covers basic risk adjustment DCF capital budgeting techniques, along with both their strengths and weaknesses.

2.4.2 Basic Risk Adjustment Techniques in Capital Budgeting

Of the shortcomings and deficiencies of DCF techniques listed, it is clear that the most persistent flaw is the inability to account for risk. In addition, DCF techniques overestimate risk in an effort to account for all risks prevalent in an investment decision over its discounted life. Due to this, advancements in DCF methods have considered basic risk analysis methods. These methods include, discounted payback, the Certainty Equivalent (CE) method and the Risk Adjusted Discount Rate (RADR). None of these methods can actively eliminate risk, however, they do provide a means of vindicating risk in its incorporation in the capital budgeting of investments. The two primary methods discussed in this chapter are the CE and RADR methods.

The Certainty Equivalent Method

The CE method was conceptualised by Robichek and Myers (1966) to establish a cash flow that could be accepted with greater certainty explains Baker (2011). The further cash flows are projected into the future the more difficult it becomes to forecast a reliable estimate. By using a CE method, future cash flows are calculated by adjusting normal cash flows by a risk factor, known as the Certainty Equivalent Factor (CEF). Consequently, the most challenging aspect of the CE method is the calculation of the CEF. According to Clark *et al.* (1984) "*a problem with certainty equivalents is the question of perception of managers or decision makers in the regarding the degree of risk associated with the forecasted cash flow distribution and their degree of aversion to perceived risk.*" One such method of categorising risk is to separate various investments organisations undertake explains Clark *et al.* (1984), such as differentiating between replacement projects, new investments and research and development. Each category is then given its own risk factors based on historical information to create a Coefficient of Variation (CV) for each investment category. This is demonstrated in Table 2.5 below. Using Table 2.5, an example is provided to give a better understanding of the CE method.

Table 2.5: Certainty Equivalent Factors for different project categories

		Certainty Equivalent Factor			
Type of Project	**CV**	Year 1	Year 2	Year 3	Year 4
Replacement	$CV \leq 0.1$	0.95	0.92	0.89	0.85
Expansion	$CV \leq 0.25$	0.85	0.82	0.78	0.73
Replacement	$0.1 < CV < 0.25$	0.9	0.86	0.82	0.77

Adapted from Baker (2011)

Using the CE method, the future cash flows are then discounted using NPV methods. The Certainty Equivalent Net Present Value (CE(NPV)) is presented by Equation 2.9 below.

$$\mathrm{CE(NPV)} = \sum_{t=1}^{n} \frac{\mathrm{CEC}_t \times \mathrm{CF}_t}{(1+r_f)^t} - (X \times \mathrm{CEC}_0) \tag{2.9}$$

Where CEC_0 = Certainty equivalent coefficient of the initial investment amount and CEC_t = Certainty equivalent coefficient of the cash flow in period t .

Example: The Certainty Equivalent Method

Consider the capital expenditure in the expanding of a steel factory sector, the expansion costs R400 000. The steel company wants to compare the difference in a conventional NPV analysis with a Certainty Equivalent Net Present Value (CE(NPV)) analysis. The analyst uses the expansion Certainty Equivalent Factor (CEF) variables from Table 2.5 and assigns an initial CEF of 1.05 to the capital expenditure. The WACC rate used by the company is 15% and the risk-free rate is 6%. By using the cash flows over four years presented in Table 2.6 below, along with Equation 2.9 and the *Expansion* CEF factors from Table 2.5, an example of the CE(NPV) is presented.

Table 2.6: Cash flows for CE(NPV) example

Year	Cash Flow (R)
1	50 000
2	100 000
3	150 000
4	200 000

The calculation of the CE(NPV) is presented in Figure 2.5. The conventional NPV is calculated as −R67 929 while the CE(NPV) is −R93 045. It can be seen from the results that the CE method is far less forgiving on the investment as it takes further risk into account. Note that the CE method can apply risk adjustments to both future cash flows and the discount rate, making it theoretically, very dynamic.

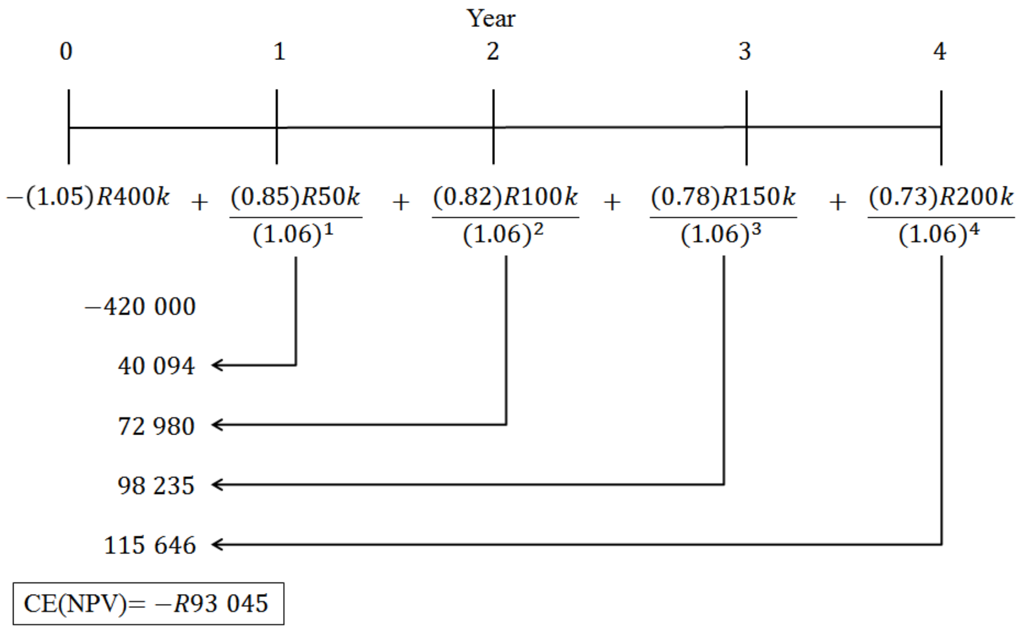

Figure 2.5: Certainty Equivalent NPV calculation

Risk-Adjusted Discount Rate

Usually when incorporating risk into DCF capital budgeting techniques, either the cash flows or the discount rate must be adjusted. The CE method accounts for adjustment in cash flow, while the Risk Adjusted Discount Rate (RADR) takes into account the adjustment of the discount rate. The general principle stipulates that a higher risk investment receives a higher discount rate, thereby lowering the NPV and setting a higher standard for investments to be accepted or rejected.

The RADR is calculated in much the same way as a conventional NPV barring the fact that instead of using a discount rate based on the WACC it is based on the RADR rate, r_d. The Risk Adjusted Discount Rate Net Present Value (RADR(NPV)) is calculated using Equation 2.10 below.

$$\mathrm{RADR(NPV)} = \sum_{t=1}^{n} \frac{\mathrm{CF}_t}{(1+r_d)} - X \tag{2.10}$$

Where r_d = the risk adjusted discount rate

The same decisional criteria applies to the RADR(NPV) as it does to conventional NPV. If it is greater then zero, then accept the investment otherwise if the result is negative, do not accept the investment.

The risk adjusted discount rate is calculated using Equation 2.11:

$$r_d = r_f + r_b + r_p \tag{2.11}$$

Where r_f = Risk free rate, r_b = Adjustment for normal business risk and r_p = Adjustment for the risk on a specific project.

As can be seen from Equation 2.11, the overall success of the RADR is based on how accurately management can determine the various rates incorporated in r_d.

Weaknesses of the CE and RADR

According to studies such as Shapiro (2005), it is found that the CE method is preferred to the RADR. This is due to fact that the CE method allows for both the valuation of future cash flows as well as the time value of money separately. In addition to this, Seitz and Ellison (1990) state that the CE method allows decision makers to integrate their own risk predictions directly into the evaluation. The most significant weakness of CE methods is the determination of the correct Certainty Equivalent Factor (CEF). The difficulty lies in the fact that no appropriate measurements exist and the result of external factors is exceptionally difficult to account for. Risk is also highly subjective and in many cases, individual preferences may differ resulting in varying influences on the investment proposal.

Interestingly, although CE is theoretically viewed to be more accurate than RADR, the latter is implemented far more frequently. In fact, a survey conducted by Kim *et al.* (1986), showed that only 7% of financial managers employed CE methods while 29% employed the traditional RADR. The primary reason RADR is applied is its apparent simplicity. The basic premise applies a higher discount rate to a higher risk investment which is appealing. In the case of a lower risk investment, cash flows are discounted at a lower rate. Ultimately, the result provides basic NPV accept or reject decision criteria. The RADR has other drawbacks, which in many aspects are similar to those of the CAPM.

Drawbacks such as determining the project beta explains Northcott (1992), while Butler and Schachter (1989) are concerned about the problem of risk estimation and its influence on the RADR. More so, a strong probability exists that given the exact same set of circumstances, various financial managers will each have different RADR values. In closing, it can be contended, that conventional DCF capital budgeting methods are only moderately successful in accounting for risk and offer basic, functional models in portraying risk and the valuation of investments.

2.4.3 Final Remarks

Traditional analysis such as DCF are beset with shortcomings and irregularities. They grossly underestimate the value associated with flexibility in investment decisions by assuming all outcomes are static and all decisions made are irreversible. In reality business decisions are governed by an ever changing and dynamic environment where managements ability to mould and adapt are crucial. Management must be both aware of changes that need to be made, as well as have the capacity to modify capital budgeting decisions made. In measuring the value attached to such decisions in a deterministic way such as using DCF, crudely underestimates the inherent value within an investment or project.

In light of these deficiencies, new metrics and techniques need to be implemented to take into account the value attached to flexibility. Real options is one such capital budgeting technique, which is built upon conventional DCF analysis. In addition it can provide value added insights into decision making by taking into account managerial flexibility and uncertainty. A unique perspective is also provided with the aid of Figure 2.6. The graph presented in Figure 2.6 consists of two axis, one with a perspective axis measuring the extent of either a bottom-up or top-down approach. The horizontal axis consists of measurements between qualitative analysis and quantitative analysis.

From Figure 2.6 it can be seen that from a bottom-up approach, concepts are more focused on micro variables compared to top-down approaches which begin their focus on a macro level. In distinguishing between levels, a top-down macro will begin with a global view, working down into working and marketing conditions and then an organisations competitive options. From

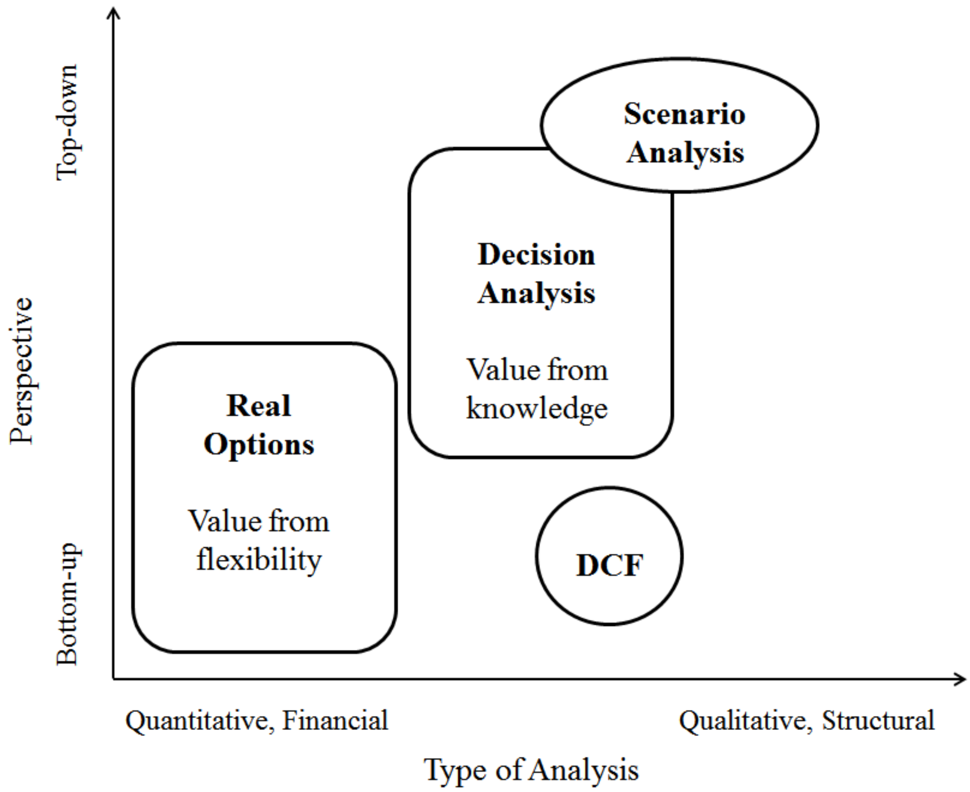

Figure 2.6: Capital budgeting: An analytical perspective

Adapted from Mun (2006)

the figure, the DCF analysis is far more structured, focusing on more micro elements and not taking into consideration global, market and economic conditions. Rendering it both static and unable to adapt. The real options side however is more dynamic, although it also has a large micro element perspective, its flexibility and view on uncertainty give it more macro perspective. It shares similar space with Decision Analysis and is also firmly in the financial and quantitative area of analysis.

The figure gives an analytical representation of the value of real options compared to that of DCF. It shows that real options considers a wider perspective of variables and firmly implements more quantitative financial measures allowing it to adapt to economic and market changes. Whereas DCF methods are more structured and consider only elements within direct relation to the investment decision, ultimately hindering its overall perception in the capital budgeting process and reaping no value through uncertain investment conditions or managerial flexibility.

2.5 Real Options

This section aims to provide a more holistic understanding of the concept of real options in light of the limitations of DCF: its history, its relevance and insight into the tools and techniques which can add significant value to investment decision making. It begins with a brief history of real options, continues to a discussion of relevant literature and then explores the practical uses of real options in industry in addition to a discussion of their advantages, limitations and popularity. Finally various techniques used in real options valuation are introduced including methods such as Black–Scholes (BS) and the Binomial Lattice. An array of key parameters and the assumptions of many valuation tools are also outlined.

Real options provide a framework for decision making under conditions of uncertainty explains Steffens and Douglas (2007), where an investments value is enhanced by the flexibility of future options. As explained by Ford *et al.* (2004, p. 2) "*options are strategies that include a right, without an obligation, to take specific actions in the future, at some cost, and contingent on how conditions, initially uncertain, evolve.*" The reference to *real options* is to differentiate them from financial assets, stocks and commodity options. According to Mun (2006) real options, use option theory to appraise physical or real assets, as opposed to financial assets or stocks and bonds. This essentially makes it applicable to physical asset investments and also within a Physical Asset Management (PAM) framework.

Myers (1977) who coined the concept of *real options* incorporated three main attributes of real options. This allowed it to stretch beyond conventional NPV analysis and consider indefinite cash flows and strategic decision making. These three attributes are (i) uncertainty of future cash flow; (ii) investment irreversibility (i.e., once a firm has started a project it cannot expect to recover the entire investment from sources other than future cash flow); and finally (iii) the timing of project commencement. In the case of real options, the manager is no longer a docile bystander, rather, the manager is an dynamic contributor in determining the cash flow structure of a project or investment. According to Baker (2011) real options add value to management through flexibility as it allows them to make critical decisions throughout the life of a project.

2.5.1 The Basics of Option Pricing

As briefly stated earlier, real options are derived from financial option pricing theory. As in most cases, the variables used from financial options are likened to suite those from a real options perspective. In order to understand where value is found in real options, it helps to understand basic financial option pricing theory. A simplified explanation as well as an *example* regarding call options is presented next.

What is a call option?

A call option gives the buyer of the option the right but not the obligation to buy an underlying asset at a fixed *strike price*[4] at any time prior to the expiration date of the option: the buyer pays a price for this right. According to Aswath (1999) if at expiration, the value of the asset is less than the strike price, the option is not exercised and expires worthless. If, on the other hand, the value of the asset is greater than the strike price, the option is exercised. The buyer of the option buys the stock at the exercise price and the difference between the asset value and the exercise price comprises of the gross profit and the price paid for the call initially.

A call option pay-off diagram is illustrated in Figure 2.7, the net pay-off is negative (and equal to the price paid for the call) if the value of the underlying asset is less than the strike price. If the price of the underlying asset exceeds the strike price, the gross pay-off is the difference between the value of the underlying asset and the strike price, and the net pay-off is the difference between the gross pay-off and the price of the call.

Example: Buying of a call option

Following the description of a call option outlined in the preceding section, a worked example is provided to illustrate the value of call options and the possibility of added value through flexibility and timing. Firstly the parameters used in the calculation need to be introduced and can also be seen in Figure 2.7. The premium paid for the call option gives the buyer of the option the right but not the obligation to buy the underlying asset at a fixed or *strike*

[4]Strike price is also known as the Exercise price

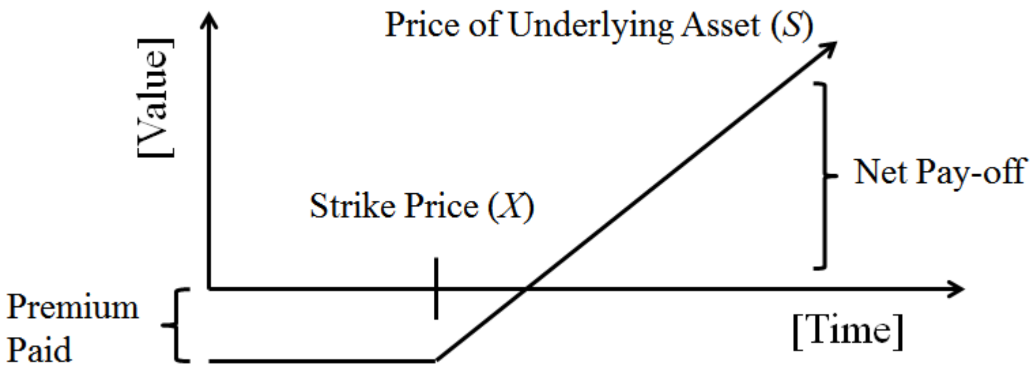

Figure 2.7: Call option pay-off diagram

Adapted from Aswath (1999, p. 6)

price (X). This remains a fixed price. The value or *price of the underlying asset* (S) is the present value of the asset which is susceptible to change and it can increase or decrease in value over time.

Using the above parameters lets consider two possibilities which can occur:

i) Assume that $X = \text{R}50$ and $S = \text{R}30$, if $S < X$, then the strike price is less than the price of the underlying asset and the buyer should not exercise the option. In this case the buyer only loses the premium paid.

ii) Assume that $X = \text{R}50$ and $S = \text{R}100$, if $S > X$ then the buyer chooses to exercise his option and buy the asset. The profit made is the difference between S and X, thus making a profit of R50, simply through exercising the option.

In essence, the premium is paid to provide the buyer with the option to exercise buying the asset or not. Should the value of the underlying asset S fall, the buyer loses his premium. On the other extreme should S increase, the buyer makes a profit. The profits in theory are arguably infinite. Table 2.7 below gives an indication of the factors which cause *call* and *put* values to either increase or decrease. A *put* option functions on the same basis as the call option, however it approaches option theory from the perspective of *selling* an option.

Table 2.7: Factors influencing call and put values

Factor	**Call Value**	**Put Value**
Increase in underlying asset value	Increase	Decrease
Increase in strike price	Decrease	Increase
Increase in variance of underlying asset	Increase	Increase
Increase in time to expiration	Increase	Increase
Increase in interest rates	Increase	Decreases
Increase in dividends paid	Decrease	Increase

Adapted from Aswath (1999, p. 9)

American Versus European Options

The primary distinction between American and European options is that American options can be exercised any time prior to its expiration explains Aswath (1999), while European options can only be exercised at expiration. The possibility of early exercise makes American options more valuable than otherwise similar European options; it also makes American options more difficult to value.

2.5.2 Real Options in Theory

It has been over three decades since Stewart Myers laid claim to the term "real options" in 1977 explains Borison (2005). According to Borison (2005), the concept attracted moderate interest, mainly among academics in the 1980's and 1990's. Initially real options referred to the theory of option pricing in the valuing of "real" investments or non financial investments with considerable flexibility. Examples of such investments outlined by Myers (1977) include multi-staged R&D as well as sectional manufacturing plant expansions. Real options are applied in cases where there is a choice concerning real investments such as capital budgeting projects, as opposed to financial investments states Baker *et al.* (2011). Among some of the more general *real options* within capital budgeting are the options to invest or not, the option to abandon or continue a project and the option to delay or carry on with the investment explains Chance and Peterson (2002). Some authors, such as Childs *et al.* (1998)

apply a real options approach to scrutinise capital budgeting for interrelated projects.

Today real options are used well beyond just capital budgeting. In some cases Teach (2003) explains that it has been used as an analytic tool in areas extending from investments, natural resources and new products to acquisitions, factories and information technology. Interestingly Amram and Kulatilaka (2000) note that there is an increase in interest in both a supply and demand of real options tools. On the supply side there is a flourishing supply of literature leaning towards real options. On the demand side is management's beneficial interest in the strategic and flexible structure which real options can provide. In fact Baker *et al.* (2011) points out that there is significant interest in industries such as mining, oil, gas, aerospace, pharmaceuticals and biotechnology to implement real options flexibility to appraise large capital investments. Real options has the potential to present more efficient ways for firms to allocate capital and maximise shareholder value by levering uncertainty and limiting downside risk explains Arnold and Shockley Jr (2002). Although real options are do not yet provide a flawless capital budgeting tool many firms are attracted to the concept given its substantially more complex mathematical foundations, flexibility and option valuation tools.

According to Mun (2006, p. 30) real options is defined as:

> *a systematic approach and integrated solution using financial theory, economic analysis, management science, decision sciences, statistics, and econometric modelling in applying options theory in valuing real physical assets, as opposed to financial assets, in a dynamic and uncertain business environment where business decisions are flexible in the context of strategic capital investment opportunities, and project capital expenditures.*

Mun (2006) regards real options crucial in the following aspects:

i) Identifying different corporate investment decision pathways or projects that management can navigate given the highly uncertain business conditions;

ii) Valuing each strategic decision pathway and what it represents in terms of financial viability and feasibility;

iii) Prioritising these pathways or projects based on a series of qualitative and quantitative metrics;

iv) Optimising the value of your strategic investment decisions by evaluating different decision paths under certain conditions or using a different sequence of pathways to lead to the optimal strategy;

v) Timing the effective execution of your investments and finding the optimal trigger values and cost or revenue drivers; and

vi) Managing existing or developing new optionalities and strategic decision pathways for future opportunities.

To better illustrate the flexibility and value associated with Real Options Analysis (ROA) an example is provided where ROA is compared with a common DCF metric, NPV. The example illustrates a broader paradigm shift in the valuing of investments when confronted with uncertain future conditions and undiversifiable risks.

2.5.3 Example: Real Options Analysis versus DCF

Consider a large, physical asset based company. The company is interested in buying new equipment to enter a new product market. The market is currently volatile and it would be preferred to make the investment decision in a years time. However, being a new product market, the company would also like the strategic advantage of being first in the market. Currently, the company is using traditional DCF capital budgeting metrics such as NPV. Due to the uncertainty associated with the investment, the company is interested in valuing the investment from a Real Options Analysis (ROA) approach.

The conditions for the investment are as follows:

i) Immediate outlay of R70 000

ii) Cash flow of R150 000 with a probability or $p = 0.6$. Or the cash flow of -R30 000 with a probability or $p = 0.4$.

iii) Rate of risk (r)= 15%

iv) Risk free rate (r_f) = 4%

By using the cash flows provided along with the relevant probabilities, the expected cash flows can be calculated as follows:

$$\begin{aligned} \mathrm{R}150\,000\,(0.6) &= \mathrm{R}90\,000 \\ -\mathrm{R}30\,000\,(0.4) &= -\mathrm{R}12\,000 \\ &= \mathrm{R}78\,000 \end{aligned} \tag{2.12}$$

Due to the premise of conventional DCF, all factors affecting the investment outcome are reflected by the NPV. From the DCF prespective, once started, investments are managed passively and cash flow streams remain fixed. In addition all risks associated with the investment are assumed to be covered by the discount rate. The expected cash flows in Equation 2.12 are discounted to the Present Value (PV) using the discount rate r. PV = R78 000/1.15 = R67 826. The NPV is now calculated and shown in Equation 2.13. According to NPV conditions, the investment should not be accepted as NPV < 0.

$$\mathrm{NPV} = \mathrm{R}67\,826 - \mathrm{R}70\,000 = -\mathrm{R}2\,174 \tag{2.13}$$

The flexibility of ROA can provide better timing of investments, more time allows for more information, allowing more reliable investment decisions. If the alternative option is taken and the investment decision is delayed for a year, conditions alter significantly. The initial outlay required is only R10 000, with a delay of spending a further R60 000. Within an extra year (delayed), it will be known whether the investment cash flows are either R150 000 or −R30 000. If the cash flow is R150 000, the company will readily invest the remaining R60 000. In Figure 2.8 the difference in options can be seen if the R60 000 investment is delayed. Figure 2.8 will now be discussed in more detail, along with its corresponding NPV calculations.

If the R10 000 outlay is made at *time 0*, and the expected cash outlay of R150 000 at *time 2* is known at *time 1* (delayed decision by 1 year). The NPV at time 1 can be calculated as shown by Equation 2.14 by using the risk free rate as expected cash inflows are more certain.

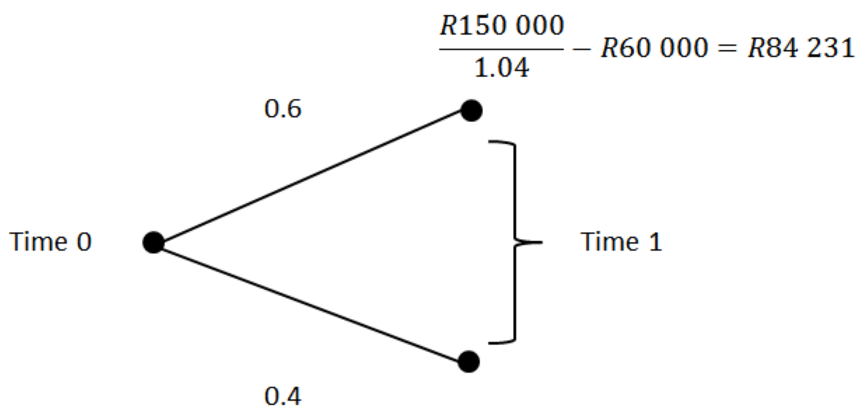

Figure 2.8: Option to delay R60 000 payment outlay

$$NPV_{\text{time 1}} = \frac{\text{R150 000}}{1.04} - \text{R60 000} = \text{R84 231} \tag{2.14}$$

The initial decision, however, is made at time zero, so to calculate the NPV at *time 0*, the expected probability of the option (0.6) is used, thus R84 231(0.60) = R50 539 and also discounted to the PV with r (15%), thus R50 539/1.15 = R43 947. The NPV at time zero can now be calculated as demonstrated in Equation 2.15.

$$NPV_{\text{time 0}} = -\text{R10 000} + \text{R43 947} = \text{R33 947} \tag{2.15}$$

This presents a substantially different result as in this case, the investment would be readily accepted with an $NPV > 0$.

In comparing the final results generated, there is a large discrepancy between conventional DCF and ROA approaches. What is important to note in this example is that there were no significant new equations used. In both cases, the conventional NPV method was used. The key difference however, was in the way the investment decision was viewed considering the conditions. The first calculation represented a conventional static NPV approach. In this approach, one discount rate was used to evaluate an investment based on inconclusive future cash flows. The investment decision was passively managed and the cash flows were viewed as fixed.

On the other hand, real options embraced both the risk as well as the uncertainty of the investment. By applying flexible, real time investment thinking, the investment decision was broken up into various time phases. By applying an NPV method within the uncertainty of future cash flows, it was possible to identify added value. Granted, the company had to spend R10 000 in order to gain insight into the future cash flows by waiting a year, but in the end it was justified. It will be more beneficial to spend a premium amount in gaining further insight and losing the premium, than either investing blindly, or worse, missing what could be a very profitable and strategic investment option.

2.5.4 Real Options Analysis Parameter Descriptions

Before discussing the various Real Options Analysis (ROA) techniques this section provides an explanation of the common parameters used in ROA. Real options stems from financial option theory, thus parameters used in the valuation of physical assets are likened to those used in financial option valuation. The next section will provide a more detailed explanation of option pricing tools, however, the Black–Scholes (BS) option pricing calculator is regarded as the foundation of option pricing. The parameters outlined are based on the parameters used in the BS option pricing equation. The parameters defined compare real, physical asset based parameters to conventional option pricing parameters.

Underlying Stochastic Process

In terms of modelling an option there are two primary concerns emphasised by Miller and Chan (2002), the first being the movement of the real asset over time with the second being the real assets tradability within the market. In terms of the decisions made, either continuous or discrete time approaches can be used, this however is not particularly an issue as Damodaran (2002) has proven. As discrete simulation steps get smaller and the price process becomes continuous the discrete binomial method converges to a continuous time model such as BS. There are however, three varying stochastic processes which Hull (2009) believes alter the results of real options valuation, namely: A Poison jump process, a mean-reverting process and Geometric Brownian

Motion (GBM)[5]. BS assumes a GBM assumption, which is a standard diffusion process used for an underlying security, it is very popular and used in most ROA. Poisson jumps are normally implemented in imitating sharp, unexpected movements which cannot be understood through traditional GBM. The mean-reverting process mentioned describes the value attached to an asset, but has an inclination to revert to past averages over time. According to Copeland and Antikarov (2002), both the mean-reverting and the Poison jump process run the risk of over valuing the option presented.

In the study presented the BS model will use a GBM stochastic[6] process to value real options within a Physical Asset Management (PAM) framework. The parameters needed to complete the BS equation are now presented. Each parameter is described according to its financial option pricing foundations.

Stock Price (S)

The stock price is also considered as the present value of future cash flows obtained from the investment of an option. This is usually done by discounting future cash flows against some discount rate to present values. In the study, a conventional discount rate will be used based on either industry standards or the widely accepted Weighted Average Cost of Capital (WACC), which is generally based on a Capital Asset Pricing Model (CAPM) in the risk factored pricing of assets.

Risk and Discount Rate (r_f)

Real options, as with financial options, assume the use of a replicating portfolio consisting of either an underlying traded asset or a risk free bond. This is used to hedge risks within an options value, and is assumed a risk-free rate. The assumptions according to Trigeorgis (1993), Mason and Merton (1984) and Copeland and Antikarov (2002) are to treat the underlying tradability of real options valuation like that of financial options. In short, the risk-free rate used covers all areas of discounting. In most cases the risk-free rate chosen comes

[5]Brownian motion is the presumably random moving of particles. The mathematical model has real world applications such as presenting stock market fluctuations.

[6]A stochastic process or random process, is a collection of random variables. Often used to present the evolution of a random value or system over time.

from a similar replicated portfolios such as low risk (risk-free) government bonds or a savings plan.

Volatility (σ)

One of the major parameters influencing the option value of a real asset is volatility, in particular, choosing the most suitable volatility or standard deviation for the particular asset explains Miller and Chan (2002). In the case of ROA there are three primary forms of estimating volatility, according to Luehrman (1998a) they are: Taking an educated guess; gathering historical data, and simulation. While Miller and Chan (2002) argue the availability of usable historical data for real options, this can be seen as purely circumstantial. According to the three primary forms identified above,the resultant approaches in estimating volatility in literature are: twin security information, Monte Carlo simulation, and closed-form expressions. Each of the above has been used in a variety of applications, authors Kelly (1998) and Smit (1997) used twin security techniques to estimate the volatility of natural resource projects using the futures market. On the other hand, Copeland and Antikarov (2002) estimate the volatility of there respective projects by using Monte Carlo simulation.

This study bases volatility measures on industry standards and historical data by using a case study that presents investments with an PAM environment.

Exercise Price (X)

The exercise price for a real options analysis is representative of the cost incurred in initiating the next phase of investment, or the revenue received for an abandonment option explains Miller and Chan (2002). It differs from the exercise price of financial options largely due to to closed-form equations developed by Carr (1988), Margrabe (1978) and Fischer (1978) as well as the flexibility found in lattice models. The difficulty however lies in the fact that often real options cannot be assumed to be one lump sum amount like financial options, instead it could be in various instalments. Although some authors feel this is necessary to be addressed, it is extremely difficult and literature has not clearly addressed the issue. Instead authors such as Teisberg (1994) used lumpy and sequential cost proposals in valuing the construction of a utility power plant.

For the focus of this study, a fixed investment exercise price is used. Using lumpy or broken up instalments is both complicated and tedious. For this study it is more important to convey the overall concept of a real options analysis within a PAM framework, thus the choice of using a fixed exercise price.

Exercise Time (t)

Due to the nature of real options analysis, the correct date used in the valuation mat not be clearly defined or else is more of an assumption. Although this may appear vague, the value it aspires is both flexibility as well as uncertainty. Firms can use educated guess work or base exercise date decisions on phases of the investment plan, this is where multi-scenario planning, which will be included in this study can be useful. Miller and Chan (2002) point out factors such as competition, technology changes, macroeconomic factors and firm specific risks as some of the key issues surrounding real option timing.

The parameters outlined in accordance with the BS call option calculator are pivotal as the literature moves into the next section which introduces various types of real option valuation tools.

2.6 Real Option Valuation Techniques

There are two primary modelling approaches used in the valuing of real options as demonstrated in Table 2.8, they are discrete- and continuous-time approaches. These approaches are outlined in option pricing techniques and are applied to real options by authors such as Hull (2000), Wilmott (1998), Dixit and Pindyck (1994) and Copeland and Antikarov (2002). Discrete-time approaches include multinomial lattices such as the binomial lattice and the adjusted decision tree approaches. Continuous-time approaches consist of a few categories such as closed form equations, stochastic differential equations and simulation approaches. Table 2.8 provides a summary of the various option calculators referred to along with their respective advantages and disadvantages. The sections to follow outline each method in further detail as well as provide formal calculations and variable definitions.

Table 2.8: Call option modelling approaches

Option Calculator	Advantages	Disadvantages
Discrete-Time Calculators		
Multinomial Lattice	Intuitively Appealing	Cumbersome
	Flexible	Labour Intensive
	Easy Implementation	
Continuous-Time Calculators		
Closed Form	Simplified Calculations	Limiting Assumptions
	Straightforward	Limited Applicability
Stochastic Differential Equations	Model Flexibility	Approximate Solutions
	Mathematically 'Accurate'	Complicated
Simulation	Adaptable	Require Special Skill
	Broad Applicability	Potential Misuse

Adapted from Miller and Chan (2002, p. 117)

2.6.1 The Binomial Option Pricing Model

Introduction to Lattice Valuation Approaches

According to Miller and Chan (2002), the lattice approach forms a *tree-like* structure as it treats an asset as a discrete, multi-decisional, multiplicative stochastic process over a certain time period. Using the nodes formed at these decisional points on the tree, the option value is then calculated for the multinomial lattice. Some of the key advantages of using the lattice approach include very perceptive and natural valuation procedures as well as malleable valuation processes. The decision process is mapped out in a tree like structure, allowing the decision maker to observe the option value, structure and resulting affects at various nodal points.

Lattice approaches have been used extensively in ROA financial literature and have adapted over time to encompass real asset valuation options. The standard binomial lattice method was developed in 1979 by Cox *et al.* (1979) as well as by Rendleman and Bartter (1979). Lattice methods, were extended twice in the 1980's by Boyle, the first was the trinomial tree by Boyle (1986), with the second being the five-jump tree explained in Boyle (1988). The real options multinomial case was made apparent and popularised as the "He" model in 1990 states Herath *et al.* (2001). By 1993, authors such as Tian (1993) established both binomial and trinomial models suitable for real options analysis. Real options lattice approaches can be seen in examples such as Pickles and Smith (1993) and Smit (1997) in the petroleum industry.

Binomial Lattices

According to Mun (2006), in the case where there is risk or volatility in an investment or a projects cash flow and there is an accumulating rise in uncertainty over time; the option value can be approximated by using a binomial lattice valuation model. As the uncertainty within a project grows, so too does the lattice which becomes wider ultimately increasing the value of the option. Binomial lattice methods are a type of open-form discrete simulation as opposed to Black-Scholes which is a closed-form continuous valuation method explains Mkhize and Moja (2009). Although binomial lattice follows discrete simulation Damodaran (2002) has proven that as these simulation steps get smaller and the price process becomes continuous, the discrete binomial method converges to a Black-Scholes option pricing model. This is explained in greater detail within the Black-Scholes Section 2.6.2.

Mun (2006) also points out that even if the project risk or volatility (σ) stays constant, the level of uncertainty still increases over time at a rate of ($\sigma\sqrt{\partial t}$). That is the level of uncertainty increases at the square root of time, thus the more time that passes, the harder it becomes to predict future returns. Mkhize and Moja (2009) make an interesting statement which is that uncertainty drives the value of options in projects and investments. In a binomial lattice method, cash flows of a project are represented as points on a lattice, such as in Figure 2.9 below.

The first point on the lattice at point zero is the present value of the under-

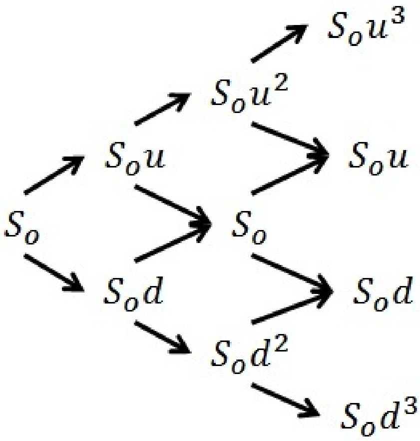

Figure 2.9: Binomial lattice representation for option valuation

lying investment or the cost of saving. The method, as stated by Mkhize and Moja (2009) calculates state-dependent present value factors and multiplies them with state-dependent cash flows.

Benninga and Tolkowsky (2002) state that the node of each tree is discounted by the appropriate state price of each node. Thus the NPV of the project is a sum of all discounted cash flows less the initial costs. Further Mun (2006) explains that the lattice is calculated using two main steps. The first step is to calculate the binomial asset lattice which requires an *up* (u) and *down* (d) factor as in Equations 2.16 and 2.17 below.

$$u = e^{\sigma\sqrt{\partial t}} \tag{2.16}$$

$$d = e^{-\sigma\sqrt{\partial t}} = \frac{1}{u} \tag{2.17}$$

Where: ∂t = the step size, and the step size is calculated as follows:

∂t = Time to maturity of the option/Number of lattice steps

From Equations 2.16 and 2.17 the up factor is simply the exponential function of the volatility of the cash flow returns multiplied by the square root of time steps. The volatility is an annualised value, multiplying it by square root time steps breaks it down into the time-step's equivalent factor. The higher the volatility, the higher the up and down factors, and the wider the lattice becomes. The risk neutral probability (p) is calculated as follows in Equation 2.18 by Mun (2006, adapted by Mkhize and Moja (2009)).

$$p = \frac{e^{\left(r_f - q\right)(\partial t)} - d}{u - d} \tag{2.18}$$

Where $q =$ the dividend

In this real options presentation however, it is assumed that no dividends are payable, Equation 2.18 thus changes to Equation 2.19 as explained by Svavarsson (2004).

$$p = \frac{e^{\left(r_f\right)(\partial t)} - d}{u - d} \tag{2.19}$$

According to Mun (2006), the probability is a mathematical factor used in the lattice calculation, however further than that it has no specific relevance. The illustration in Figure 2.9 demonstrates how the binomial lattice begins with a present value of S_o at time zero. The value (S_o) is then multiplied by up (u) and down (d) factors to create the up and down binomial lattice.

Example: Binomial lattice real options analysis

Following the binomial lattice parameter outline this example serves to illustrate the use of a binomial lattice in real option valuation. Consider a mining operation where a large investment is made in mining vehicles transporting raw materials from the mine. The organisation is to spend R100 million on the buying of vehicles and the predicted cash flow as a result of buying the assets is also R100 million. The risk free rate or r_f defined for the project is 5% and the project can be deferred for the period of one year. The volatility σ or standard deviation accounting for the risk associated with the investment of the mining vehicle is 25%. In simplifying the example, only three time steps are used, in general however, the more time steps implemented, the more accurate the result. Table 2.9 below provides a summary of the investment variables defined.

Table 2.9: Summary of parameters: Binomial lattice example

Variable	Call Option	Value
S	Stock price	R100 million
X	Exercise price	R100 million
t	Time to expiration	1 year
r_f	Risk free rate of return	5%
σ	Volatility of returns	25%
∂t	Step size	1/3

According to NPV calculations of the asset based investment, the investment breaks even, adding little value. NPV $= S - X =$ Rm100 $-$ Rm100 $= 0$. The binomial lattice approach values the flexibility and uncertainty of the project. The branch tree-like decisional pattern allows various scenarios to be plotted, the smaller the step size, the more granular the binomial tree and the more accurate the real option variable.

Step 1: Lattice development of underlying asset value

The first step needed in solving the binomial lattice is to calculate the up (u) and down (d) step sizes and the risk-neutral probability. This is done using Equations 2.16, 2.17 and 2.19 respectively The step size is calculated by dividing the time of the investments by the amount of steps used. In this case three steps in one year, thus $\partial t = 1/3$.

$$u = e^{\sigma\sqrt{\partial t}} = e^{0.25\sqrt{0.333}} = 1.155$$

$$u = e^{-\sigma\sqrt{\partial t}} = e^{-0.25\sqrt{0.333}} = 0.866$$

$$p = \frac{e^{r_f(\partial t)} - d}{u - d} = \frac{e^{0.05(0.333)} - 0.866}{1.155 - 0.866} = 0.522$$

Using the up and down factors the underlying asset value of the investments future cash flows are predicted. The up and down values represent variations in future cash flows according to the volatility associated with the asset. The up and down compounding takes place over three time steps within one year of deferral as seen in Figure 2.10. The binomial lattice predicts that the future value of cash flows or the value of the underlying asset (S) can be between R75 million and R174.9 million.

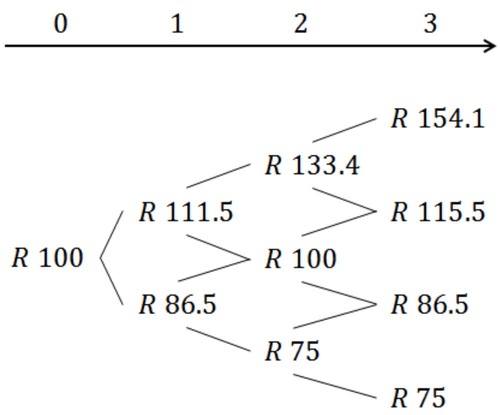

Figure 2.10: Binomial lattice: Evolution of underlying asset value

Step 2: Calculating the real option value

Figure 2.11 refers to the backwards calculation of the option value. By using the risk neutral probability as well as the intermediate value equation represented by Equation 2.20, the real option values can be calculated through backward induction from the terminal S values as shown in Equation 2.20.

$$\text{Value of option} = [(p)up + (1-p)down]\, e^{(-r_f)(\partial t)} \tag{2.20}$$

A sample calculation using Equation 2.20 is presented below to provide a better understanding of how the option value is calculated.

$$\begin{aligned}\text{Value of option} &= [(0.522)(21.7) + (1 - 0.522)(4.1)]\, e^{(-0.05)(0.333)} \\ &= \text{R13.1 million}\end{aligned}$$

Using this backward induction calculation starting at step three, the option value associated with the asset is calculated at time zero.

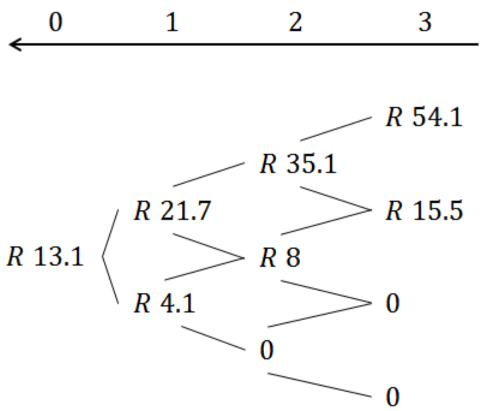

Figure 2.11: Binomial lattice: Calculation of option value

By taking the option value as well as the value of the underlying asset into account the investment looks far more favourable. The organisation affected now has more insight into the future earnings of the cash flow and risk adjusted option values associated with the volatility (σ) value. The binomial lattice real option valuation tool has assigned a further R13.1 million to the project, as it considers both a risk profile as well as active managerial flexibility.

2.6.2 Black-Scholes Option Pricing Model

There are several option valuation methods established in ROA collected works. Specifically, there are four closed-form equations that have been developed for ROA, they are Black-Scholes, Geske, Margabe and Carr. The first closed-form equation was developed by Black and Scholes (1973) and was used to value financial options and warrants. Although other closed-form equations are used, a vast majority of option valuation tools stem from the Black-Scholes equation. The widespread adoption of Black-Scholes closed-form equations comes from simplified and straightforward calculations. Accompanying these advantages however, are limiting assumptions which need to be recognised and carefully made aware of in correctly applying these equations. The Black-Scholes equation has the ability to value the options of growth, abandonment and the delaying of particular investments.

There are some key differences between Black-Scholes and other closed-form equations. In the exercise price of an asset, Black-Scholes adopts a deterministic price says Miller and Chan (2002), whereas Margrabe (1978) considers the exercise price as a stochastic variable. The model developed by Geske (1979) uses a deterministic exercise price to value compound options used in successive investment decisions, such as R&D technology investments. In response to Geske's model, Carr (1988) created a method to value similar compound option circumstances using a stochastic process. Problems represented by these equations can be seen in studies by Taudes (1998) and Lee and Paxson (2001) which compare all four equations.

The Black-Scholes model makes use of an option pricing formula. According to Mun (2006, p. 124) the *European* call option is calculated using a general Black-Scholes model as follows:

$$\begin{aligned} \text{BS call value} = & Se^{-q(t)}\Phi\left[\frac{\ln(S/X)+(r_f-q+\sigma^2/2)t}{\sigma\sqrt{t}}\right] - \\ & Xe^{-r_f(t)}\Phi\left[\frac{\ln(S/X)+(r_f-q-\sigma^2/2)t}{\sigma\sqrt{t}}\right] \end{aligned} \tag{2.21}$$

Where $q =$ The dividend and the other inputs are outlined in Table 2.10.

In the application of real options in this study, the assumption is made that there are no dividends payable, thus Equation 2.21 is rewritten as follows according to Mun (2006, p. 124)

$$\begin{aligned}\text{BS call value} =& S\Phi\left[\frac{\ln(S/X)+(r_f+\sigma^2/2)t}{\sigma\sqrt{t}}\right]- \\ & Xe^{-r_f(t)}\Phi\left[\frac{\ln(S/X)+(r_f-\sigma^2/2)t}{\sigma\sqrt{t}}\right]\end{aligned} \tag{2.22}$$

Where Φ = the cumulative standard normal distribution

The inputs for Equation 2.22 Black-Scholes call option are explained in Table 2.10 which follows. The option parameters used are based on assumptions made by Athwal *et al.* (2005, p. 13). The stock price (S) or the value of the underlying asset is equal to the present value of the cost of savings realised when a new system is deployed. The *strike price* is also known as the investment cost (X); (t) is the lifespan of the project which has a *volatility* or risk (σ); finally (r_f) is the *risk-free rate* hedging the value of money against inflation over time. Black-Scholes is used in this study to calculate simple (single stage) options such as options to expand. Damodaran (2001) maintains that in the case where options are not necessarily exercised early (before expiration) and no dividends are payable, then a dividend-protected options valuation technique can be implemented.

Table 2.10: Mapping an investment opportunity onto an financial call option.

Investment Opportunity	**Variable**	**Call Option**
Present Value of cash flows obtained from the investment option	S	Stock price
Present value of the expenditure required for project expansion	X	Exercise (Strike) price
Period that project expansion option is available for	t	Time to expiration
The South African prevailing bond rate	r_f	Risk free rate of return
Uncertainty in the cash flow generated by the investment option	σ	Volatility of returns

Adapted from Athwal *et al.* (2005, p. 110)

Benninga and Tolkowsky (2002) state that Black-Scholes is by far the most numerically flexible model there is for valuing options. In the valuation of real options, Black-Scholes is acceptable as at its best it closely resembles the actual option value. When Black-Scholes is applied in real options scenarios the model reflects an approximation to the option value fundamental in real options.

Example: Black-Scholes

The example calculated here uses the same information as that of the binomial lattice. The main reason is to give an illustration of how discrete-time calculators such as binomial lattices can approximate to continuous time models such as Black-Scholes.

Using the information from Table 2.9 and the dividend adjusted Black-Scholes Equation 2.22, the call option value is calculated.

$$\begin{aligned}\text{BS call value} =& 100\Phi\left[\frac{\ln(100/100)+(0.05+0.25^2/2)1}{0.25\sqrt{1}}\right]- \\ & 100e^{-0.05(1)}\Phi\left[\frac{\ln(100/100)+(0.05-0.25^2/2)1}{0.25\sqrt{1}}\right] \\ =& \text{R}12.34 \text{ million}\end{aligned}$$

As stated earlier, as a the number of time steps increases in a binomial lattice, the results become more accurate. In the binomial lattice example only three time steps were implemented and a result of R13.1 million was generated. Table 2.11 below illustrates how if more time steps are implemented the binomial lattice converges to the Black-Scholes value.

From Table 2.11 it can be seen that at the limit, when the number of time steps approach infinity and when the time steps become infinitely small then the discrete-time approach converges to that of a continuous time model such as Black-Scholes. Due to this reason, Black-Scholes is used in this study to give a reasonable representation of the option value associated with real, physical asset investments.

Table 2.11: Convergence of a Binomial lattice value

Number of steps	Value
3	R13.1
10	R12.093
50	R12.287
100	R12.311
1 000	R12.333
10 000	R12.335

Simulation

Simulation is a very powerful and beneficial tool to value not only financial options, but also real options. In valuing both multinomial lattices or creating complex stochastic differential equations, the process not only becomes laborious but extremely multifaceted explains Miller and Chan (2002). Simulation has simplified this process in many cases, such cases are provided in Hull (2000) and Wilmott (1998). The most commonly implemented simulation technique is Monte Carlo simulation, however considering the advantages and potential strengths and variations in using Monte Carlo simulations in valuing real options, few papers implement it. Reasons for this range from complexity, to understanding as well as general misuse. An interesting paper by Rose (1998) implements Monte Carlo simulation to value the real options within a large infrastructure project. In the scope of this study, simulation approaches are not considered as the Black-Scholes equation allows for more flexibility as well as more straightforward implementation.

2.7 Real Options In Industry

Since the inception of real options the interest attracted by academics alike has been significant. Numerous books have been published on real options by authors such as Amram and Kulatilaka (1999); Chance and Peterson (2002); Copeland and Antikarov (2002); Mun (2006); Guthrie (2009), just to name a few. In addition there are hundreds of published articles on the topic of real options along with various applications. Contrary to this, however, is the general lack of interest by top management in accepting and adopting some form of real options valuation. This is backed by Chance and Peterson (2002, p.95) who state that "*Empirical research has provided some, but very limited, support for the real-world applicability of real options models.*" In addition surveys by Triantis and Borison (2001); Graham and Harvey (2001); Ryan and Ryan (2002); Brounen *et al.* (2004) and Block (2007) preformed in Europe and the United States document the small percentage of firms which use ROA techniques in capital budgeting. Mathews *et al.* (2007) find that the development of real options is impeded by the complexity of real options techniques and the difficulty in matching real options to incorporate strategic decision-making.

Clearly the complexity or lack of knowledge on real options has hindered its acceptance as a capital budgeting tool in most firms. According to survey evidence, the majority of firms have been unhurried in implementing real options. In a survey by Graham and Harvey (2001) involving 392 CFOs, real options was ranked eighth among twelve capital budgeting techniques considered, with 27% of those who responded using the technique always or almost always. In a European study of 313 CFOs by Brounen *et al.* (2004) the results are very similar to those of Graham and Harvey (2001) with respect to the ranking and the use of real options. In a study by Ryan and Ryan (2002) on 205 *Fortune 1000* CFO's it was found that real options was implemented only 11.4% of the time. According to Teach (2003) in a report of the results of a *Bain and Company* survey carried out in 2000 of 451 senior executives from 30 different industries concerning management perceptions only 9% were found to be using real options. According to these surveys however the authors have limited their analysis of real options relative to the use of the other capital budgeting techniques explains Baker *et al.* (2011)

In his survey Block (2007) concentrates on real options and capital budgeting within *Fortune 1000* companies. Out of a field of 279 responses only 14.3% (40) of managers use real options. Interesting to see is that the 14.3% of real options users come from highly specialised and technical industries such as technology, utilities and energy. Further results of the survey show the most common areas of real options application such as new product introduction (36.2%), research and development (27.8%), mergers and acquisitions (22.1%), foreign investment (9.6%) and other (4.3%). The most commonly used real options techniques in these scenarios are binomial lattices, risk-adjusted decision trees and Monte-Carlo simulation. Some of the main reasons why real options valuation was not used was a lack of top management support (42.7%); discounted cash flow is already a proven method (25.6%):real options are too sophisticated (19.5%); and real options encourage excessive risk taking (12.2%).

Besides these figures however there are numerous industry leaders which have embraced real options. Real options initially started in the oil, gas and mining industries with expansions into biotechnology, pharmaceuticals and now high-tech industries such as telecommunications and software engineering explains Mun (2006).

Real options are used by General Motors (GM) in the auto mobile industry to create *switching options* in the production of new automobiles. In essence what this allows GM to do is use a more cost effective resource over a specified period of time. GM has a variety of suppliers it buys raw materials from. Often, prices of materials can become expensive in some regions compared to others. By implementing switching options, GM profits from using various suppliers in the fluctuations of various raw material costs.

Deferment options have been used by HP-Compaq in their forecasting of printer sales in foreign countries. Before, printers were assembled and shipped to various countries based on demand, however due to the slow assembly versus delivery time, demand changed faster than production needs and this led to either high stock levels or the production of obsolete printers. By exercising a deferral option, HP-Compaq decided to build assembly plants in other countries. This meant parts could be shipped with the specific assembly done in each country according to demand and excess parts could be sent to different countries which need them.

From a real estate perspective undeveloped land can be assigned an option of building later at better material and building costs. What is the optimal time to wait? By using real options an optimal time can be determined based on the value-to-cost as well as uncertainty attributes of market conditions.

In the Telecommunications industry companies had to install major fibre optic cabling and other infrastructure ahead of other companies to ensure that they secured strategic advantage. This was a massive growth option that would have involved serious capital expenditure on physical assets with little knowledge of future cash flows or revenues generated. It would have been a nightmare trying to convince financial directors to spend the capital needed were it not for the value accounted for by real options analysis. A Harvard Business Review (HBR) quote from a September/October issue in 1998 found in Mun (2006) sums up real options from an industry perspective:

> *Unfortunately, the financial tool most relied on to estimate the value of strategy is the discounted cash flow which assumes that we will follow a predetermined plan regardless of how events unfold. A better approach to valuation would incorporate both the uncertainty inherent in business and the active decision making required for a strategy to succeed. It would help executives to think strategically on their feet by capturing the value of doing just that—of managing actively rather than passively and real options can deliver extra insight.*

2.7.1 Reason for not using Real Options

Based largely on the statistics given in the previous section, this section attempts to outline four major reasons which inhibit the widespread use of real options based on Table 2.12 below:

While these results can take on a number of meanings what is most prevalent is the hesitance of top management to adopt and accept a capital budgeting approach that they cannot follow step by step. In fact according to Block (2007), top management felt as if *mathematics* was making decisions and bypassing *their* judgement. Another view by Van Putten and MacMillan (2004) was that real options could not be reduced to “go” or “no-go” options in making investment decisions. This view was seen as demeaning and condescending towards top management as it limited top managements apparent power.

A second reason for not using real options is based on the principle that DCF methods have already been proven to work and thus are favoured. Be-

Table 2.12: Reasons for not using real options

Reason	% **Amount**
Lack of top management support	42.7
Discounted cash flow is a proven method	25.6
Requires to much sophistication	19.5
Encourages to much risk taking	12.2
	100

Source: Block (2007, p. 261)

sides DCF methods such as NPV and IRR being highly popular, they are also highly praised in literature. This is done by downplaying methods such as payback period and average rate of return however in hindsight this should carry little influence as these methods are not only inferior and outdated but also form some of the foundations to DCF methods explains Copeland and Antikarov (2002). In this case human perception, habit and culture are to blame for not accepting real options. It can also be due to the perceived sophistication of real options, which intimidates top management.

Penultimately, the third major reason why real options are not used is related to the sophistication and difficulty of using real options. In general the highest use of real options is within the technology sector, more specifically energy, utilities, etc., which coincides with decisions made by management in those sectors having either an engineering or technology background explains Block (2007). Differently, in industries such as retailing, food processing and publishing, real options had almost no utilisation. It is thought that an accountant or someone with an MBA qualification would be less likely to participate in mathematically involved real options than an engineer or someone with a scientific background continues Van Putten and MacMillan (2004).

The final reason given for the non utilisation of real options is that it can encourage risk taking, an extract by Van Putten and MacMillan (2004) is provided to highlight this view from top management:

For all their theoretical attractiveness as a way to value growth

> *projects, real options have had a difficult time catching on with managers. CFO's tell us that real options overestimate the value of uncertain projects, encouraging companies to over invest in them. In the worst case, they grant excessively ambitious managers a licence to gamble with shareholder's money.*

This is an unfortunate result as the initial idea was to provide a way to attach value to managerial flexibility and value the option in uncertain conditions. Instead, management has taken a negative viewpoint, seeing real options as an over valuation of investments in uncertain conditions. This once again can be put down in many respects to the lack of understanding by academia, as well as the disinterest in encouraging the positive effects of real options. An extract from Copeland and Antikarov (2002) highlights the slow evolution of business and managers to adapt to new financial measures and capital budgeting techniques.

> *It took decades for DCF analysis to replace payback period analysis, the same will happen for real option analysis.*

2.8 Combining Discounted Cash Flow and Real Options Analysis

This section gives a detailed outline not only of the broad "combined" DCF and ROA framework, but the parameters required and the process followed to carry out the necessary analysis. The first two sections draw an extensive picture of the overall framework which combines both discounted cash flow and real options analysis to create an option mapping investment tool. The next two sections then discuss more detailed resource and parameter requirements. The real options section briefly discusses the principle options valuation tool (Black-Scholes) and the various parameters needed for the calculations as well as their significance. The final section presents a clear introduction to the value adding metrics which are key to the plotting of investments within the option mapping tool. These value adding metrics are fundamental as they use the same variables as the Black-Scholes option calculator yet when combined with the option mapping tool present a more descriptive investment decision tool.

2.8.1 Why Combine ROA and DCF?

Although real options can provide flexibility and has greater future valuation attributes, DCF valuation techniques are the foundation of all capital budgeting processes. Instead of choosing only one technique, it may be preferable combine the flexibility of real options with foundational and widely used DCF techniques. The view presented by Miller and Chan (2002) is that ROA and DCF techniques should complement one another as decision making tools, combining the various qualities each method presents. This is briefly demonstrated in Figure 2.12 where DCF methods are used in moderate and straightforward business decisions, with clear investment structures and dependable forecasts. ROA analysis and decision tools are far more suitable for uncertain business conditions where more information or flexibility is needed and are more useful in actively managing projects, through aspects such as abandonment, delay or expansion options.

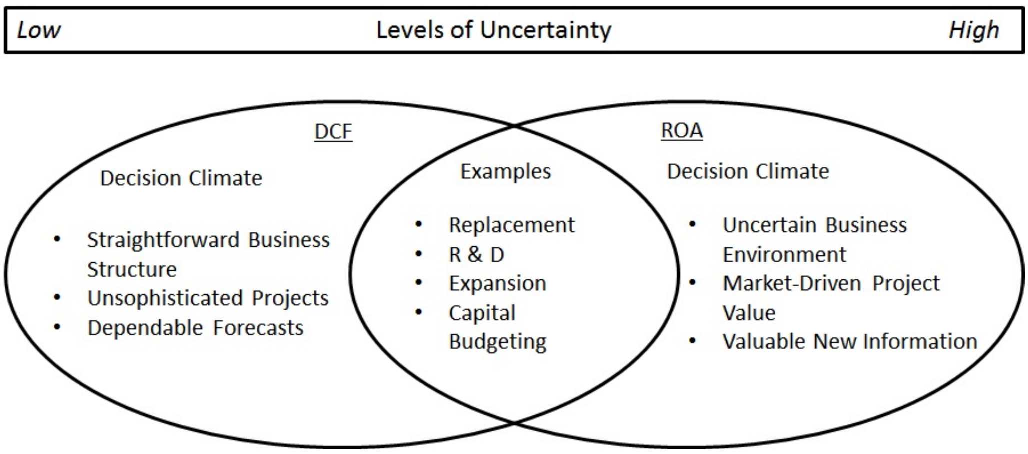

Figure 2.12: DCF and ROA compliment area

Adapted from Miller and Chan (2002, p. 110)

Dai *et al.* (2000) also suggests using an expanded NPV (extended DCF) method in valuing option-inclusive values of a project. The “expanded” NPV method can be defined as the sum of traditional NPV and the expected value of future options made possible by the initial investment. Figure 2.13 below can be used to illustrate the expanded NPV within an asset based framework. To build on the topic, the expanded NPV consists of the sum of traditional NPV obtained through DCF techniques and the value instilled in real options provided by the investment opportunity. According to Mkhize and Moja (2009) the instilled options provide management with strategic flexibility for future project expansion, deferral or abandonment. Follow-on projects in the form of compound options (options-on-options) are also possible.

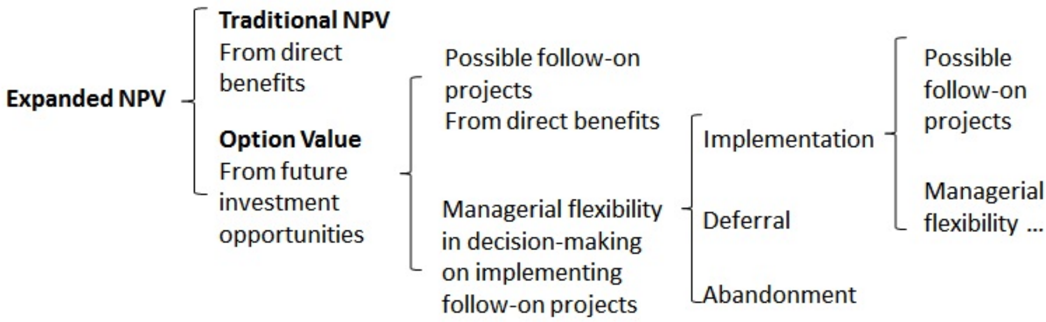

Figure 2.13: Option-inclusive extended NPV

Adapted from Dai *et al.* (2000, p. 4)

In the majority of cases, to perform a ROA, the existing information found in traditional DCF approaches is needed. Therefore DCF analysis should be performed first, then expanded upon using the advantageous ROA techniques, which will form the overlapping "compliment" area between DCF and ROA decision tools as shown in Figure 2.12. Lint and Pennings (2001) agree with the sentiments that DCF complement ROA, however the next step in project analysis is determining which of four quadrants a new investment or project falls into: The quadrants are defined according to parameters identified in Table 2.13.

In decisions based on engineering economics ties, Park and Herath (2000) divide investment categories up differently to Lint and Pennings (2001) focusing rather on varying levels of uncertainty. The higher the case of uncertainty, the more ROA decision criteria and techniques impact the final decision. A unique view from Rausser and Small (2000), find that ROA can be implemented very successfully if companies start picturing platform investments as long term profit opportunities. These platform investments are based on investing/funding a little bit at a time and waiting for new information regarding the investment potential/opportunity. Rausser and Small (2000) see these platform investments as *renting* information, in much the same way as a call

Table 2.13: Investment Analysis According to Quadrant Classification

i) **Projects with high-expected pay-off and low volatility**. These projects represent the ideal decision-making environment. Traditional DCF analysis should be performed and projects should be activated as soon as possible.	ii) **Projects with low expected pay-off and low volatility**. Traditional DCF tools should be used and the project should be abandoned as soon as possible.
iii) **Projects with high-expected pay-off and high volatility**. These projects are more representative of today's investments in technology and highly competitive markets. ROA should be utilised to quantify this risk and decisions should be made with the arrival of new information.	iv) **Projects with low expected pay-off and high volatility**. Similar to Quadrant 3, ROA should be used and these projects should only be activated with the arrival of "good" information.

Adapted from Lint and Pennings (2001)

option premium. In other words, like an option, firms should view the cost of laying the foundation for long-term investments as the price to pay for the option to enter some business opportunity in the future explains Miller and Chan (2002).

According to the December 2004 Harvard Business Review (HBR) article:

> *Companies that rely solely on discounted cash flow analysis underestimate the value of their projects and may fail to invest enough in uncertain but highly promising opportunities. Far from being a replacement for DCF analysis, real options are an essential complement, and a projects total value should encompass both. DCF captures a base estimation of value; real options take into account the potential for big gains.*

2.8.2 Value Adding Metrics

Real options see value in flexibility which can be found in active managerial decision making as well as uncertain conditions. Undeniably, there are adverse features associated with real options such as the over valuation of investments, particularly in cases with high uncertainty or large time spans. The aim, however, is to use widespread and trusted DCF techniques and supplement the decision making process with the use of more flexible, more advanced real options techniques to increase the range of investment decisions within PAM boundaries.

In order to tie up the overall theory as well as to place the data requirements in context, the next few sections demonstrate how the DCF and ROA resources are combined into an active mapping framework to create a decision making tool. The active mapping tool is based on theory by Luehrman (1998a) and uses two principle metrics to assess an investments potential. Here value is found in two areas: linking NPV to an option value as one metric and quantifying extra value through uncertain conditions as the other. This will now be explained in the sections to follow which identify where added value (lost in DCF analysis) can be found and exploited through the use of real options.

Added Value: $NPV_{\mathbf{newQ}}$

According to Luehrman (1998a), the first source of added value can be found in the interest earned on the required capital or investment expenditure by investing later rather than sooner. For example, putting just enough money into a bank account to earn interest or investing in risk free government bonds, so that when the time come to invest, that money plus the interest it has earned is sufficient to fund the required expenditure. By using Table 2.14 below to define key NPV parameters the added value metrics can be calculated.

Table 2.14: NPV and alternative investment parameters

Variable Description	**Variable**	**Value**
Present Value of a projects operating assets	S	20 million
Expenditure required to acquire assets	X	19 million
Length of time decision can be deferred	t	3 years
Risk free rate if return	r_f	5%

The conventional NPV calculated for this type of scenario would look like Equation 2.23.

$$NPV = S - X = 20 - 19 = \text{R1 million} \tag{2.23}$$

Now assume that the money is saved or invested at a risk-free rate for a period of 3 years. Discounted back the amount of money needed is shown below. Lets call the parameter PV_{invest}.

$$\begin{aligned} PV_{\text{invest}} &= X \div (1 + r_f)^t \\ &= 19 \div (1 + 0.05)^3 \\ &= \text{R16.4 million} \end{aligned} \tag{2.24}$$

Using the new exercise or investment value PV_{invest} to calculate the 'new' NPV, dubbed NPV_{new} it can be seen how the investment option has increased the value of the project through Equation 2.25.

$$\begin{aligned} NPV_{\text{new}} &= S - PV_{\text{invest}} \\ &= 20 - 16.4 \\ &= \text{R3.6 million} \end{aligned} \tag{2.25}$$

Note that the NPV_{new} will be greater than or equal to the regular NPV as it includes interest earned on money invested, while waiting to exercise an option. In considering the NPV_{new} parameter it would be far easier to adapt the NPV_{new} in such a way that it was either less than, equal to, or greater than one, in such a way that it can never be less than zero. This adaptation is implemented by taking the quotient between S and PV_{invest}. By converting NPV from a *difference* to a *ratio* all that is essentially being done is converting negative numbers to decimals between zero and one. The new equation is shown below by Equation 2.26:

$$NPV_{\text{newQ}} = S/PV_{\text{invest}} \tag{2.26}$$

NPV_{newQ} and NPV_{new} are not the same in the sense that they do not give the same answer. The difference in the final figure however does not change the interpretation of the answer which is being used. Where NPV_{new} is focused on a decision being greater than zero, in the case of NPV_{newQ} the decision is based on the answer being greater than one. Thus in terms of the interpretation between NPV_{new} and NPV_{newQ} there is a perfect match.

Added Value: Cumulative Volatility

It is extremely difficult to directly calculate added value, so instead an option pricing model can be used to measure the value given to a certain amount of *uncertainty*. The only way to measure uncertainty is through probabilities, and the most common probability-weighted measure of 'scatter' or dispersion is *variance*, often denoted as σ^2. The variance is the likelihood of drawing values away from the average, thus the higher the variance the larger the likelihood of drawing results far higher or far lower than the average, making it more risky. However, investing is also very dependant on *timing*, thus the effect timing has on the variance is also incorporated.

Based on the short explanation above a metric known as the *cumulative volatility* denoted as C_{v} is outlined using Equation 2.27 below. Expressing uncertainty as standard deviation rather than variance tells us just as much as variance does with the advantage of being denominated in the same units as that being measured.

$$C_{\text{v}} = \sigma\sqrt{t} \tag{2.27}$$

2.8.3 Exploring Option Space

This section aims to introduce and clarify the concept of a visual active mapping space. Picture a rectangular area which can be called a visual active map. The active map is regulated by two value adding option metrics, each of which capture unique value associated with the deferral of a real, physical asset based investment. The rectangular visual option mapping space is then divided up into six sections, whereby investment options can fall according to the two option metrics defined. The option mapping space can aid financial investment decision makers by actively plotting and tracking investment opportunities in a more flexible framework.

The next step of this section is to gain an understanding of both the visual active mapping space as well as the parameters and sections dividing it up. Although the two *value adding* option metrics have already been discussed, an explanation using Figure 2.14 adds significant meaning. The first parameter is the NPV metric, classified as NPV_{newQ}. In essence this metric contains all the information in a conventional NPV analysis, with the added value associated with deferring an investment. In deferring the investment, the money is invested in a replicating portfolio such as interest earning government bonds. The most basic understanding of the metric is as a value-to-cost ratio as is included in Figure 2.14 along the horizontal axis. An important point to remember is that the *value-to-cost* or NPV_{newQ} metric, refers to the asset under scrutiny and not the option on the investment.

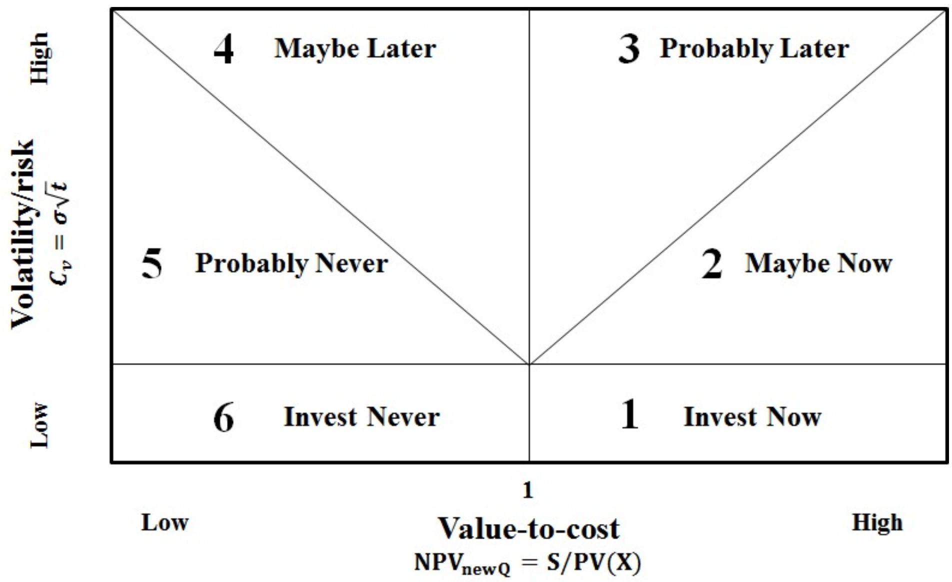

Figure 2.14: An active mapping tool with decisional criteria sections

Adapted from Luehrman (1998*b*)

When viewing an investment on the option map against the value-to-cost NPV_{newQ} axis, it is similar to that of a conventional NPV analysis. Instead of having less than or greater than zero, the defining value is one. If the NPV_{newQ} value is between zero and one, then the value of the investment is worth less than what it cost. Should the NPV_{newQ} value be greater than one, then the value of the investment is worth more than its present value cost. The second *value adding* metric defined is the cumulative volatility denoted as C_{v}. Cumulative volatility is the measure of how much an investments conditions can vary before the decision is taken. In the case presented in this study, those conditions will be based on risk parameters related to the investment decision. The cumulative volatility is made up of the *variance on the asset* (σ) multiplied by the *time to expiration* (t). The cumulative volatility is measured along the vertical axis.

The discussion now turns to the six sections included in the option space, clearly expressed in Figure 2.14. Using the two metrics aligned on either axis, the visual option mapping space is first divided with two primary lines. The first line, standing vertically starting at one on the NPV_{newQ} axis separates investments that are favourable or unfavourable according to their value-to-cost ratio. The horizontal line emerging from the C_{v} axis will be more of an asset specific guideline indicating an acceptable amount of risk. The final two diagonal lines inserted create the final division of the option mapping space into six, active decisional sections. The decisional criteria of each section is arranged according to each ones placement against either of the measuring axis. Figure 2.15 indicates in which directions value increases within the option space and coincides with the six decisional sections in Figure 3.3. Due to the value placed on risk or cumulative volatility, previously “no go” investments based on rigid NPV criteria are now given an opportunity by actively engaging in the option map.

The six sections each present an active decisional criteria which can be used to evaluate an investment. While investments with a low (less than one) *value-to-cost* ratio have less value than the present expense of acquiring the investment. Those with a higher cumulative volatility are seen in a more positive light, falling in the “maybe later” section. Although this section has a low return on investment, the option space attaches value to a higher risk profile. Investments in the ”probably never” section have little potential as not only are their returns poor, but the value adding risk profiles are also low. Moving onto the right hand side of the vertical line, these investments already portray satisfactory value-to-cost profiles. Although risk is seen to hold some value, Stellenbosch University http://scholar.sun.ac.za

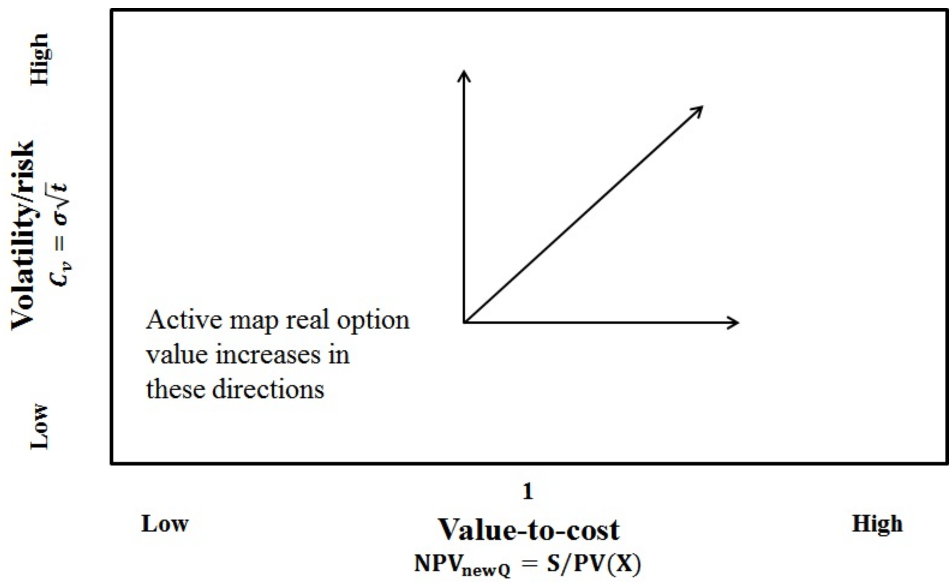

Figure 2.15: Active mapping space indicating value adding directions

risk is risk and in all financial decisions, reducing risk is always comforting. Thus the sections on the right hand side represent just that. Investments in the "probably later" section show good returns on investment however there is still a potentially high measure of risk or uncertainty. The section holds a sense of warning, indicating that the investment could still be deferred. Should the risk profile drop somewhat, the investment could move into a more favourable "maybe now" or "invest now" section.

2.8.4 The Active Mapping Tool

Building on this "combined framework" theory and on an "option mapping" framework conceptualised by Luehrman (1998*a*), the ultimate goal is to create an active mapping framework such as that illustrated in Figure 2.16. The visual mapping framework plots investment opportunities in various option spaces based on both DCF and real option metrics. In this way investment decisions can constantly be tracked and monitored. This allows decisions to become far more flexible with an active investment approach; where ultimately the parameters will indicate whether it is adequate to invest or not. Take for example the red circles in Figure 2.16 which represent the possible investment path of a decision. From the initial decision, seen as "D1" the investment is in a *Probably Never* quadrant and viewed as unfavourable. However over time the investment decision can change based on real world, real option scenarios. By actively tracking investments it can be seen that borderline investments such as "D1" develop into more favourable investments such as "D3". In addition the parameters on the active map will give an indication of which factors need to be changed, tweaked or watched in the result of borderline decisions. These parameters include *volatility*, *time*, *value* and *cost*.

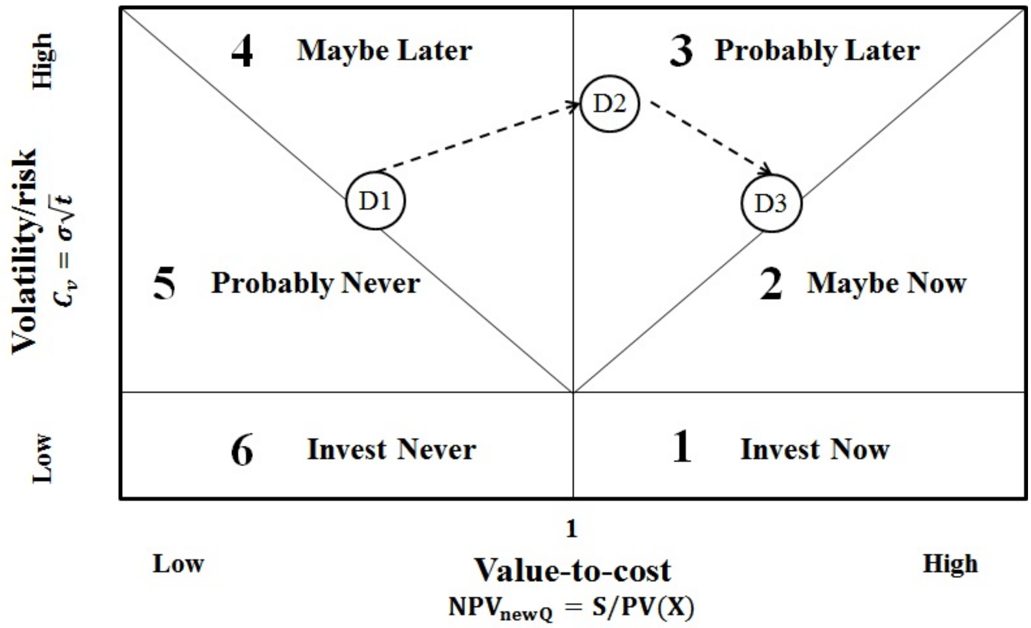

Figure 2.16: Visually integrated active mapping tool

Adapted from Luehrman (1998*b*, p. 94)

2.9 Summary

The literature study presented consists of the exploration of three core topics namely; Physical Asset Management (PAM); Discounted Cash Flow (DCF) and Real Options Analysis (ROA). The integration of these three topics forms the primary research argument which investigates the use of ROA in the capital budgeting of physical assets. The first core topic deals with the highly topical area of PAM. From literature it is understood that the management of physical assets such as plant, machinery, property, buildings and vehicles has become a greater priority for asset intensive organisations. Management of physical assets no longer just implies the maintenance and disposal of assets but instead the overall life cycle of assets from acquisition to disposal. More and more organisations are realising the influence of better physical asset management and its influence on other asset classes such as financial assets, human assets, information assets and intangible assets. Due to a need from industry for a standardised PAM framework, the Public Available Specification 55 (PAS 55) specification was established outlining the basic requirements for the effective management of assets.

Within the PAM framework, an integral phase in the life cycle of asset management is the acquiring or creating of physical assets. The primary decision tool in this phase is capital budgeting, which measures the future returns of an investment against the costs incurred. In particular, the PAS 55 specifications outline specific details in the acquisition and creation of physical assets. The primary capital budgeting technique used in the valuation of physical asset investments is DCF analysis. This naturally led to the second core topic of a broad based assessment of DCF techniques. The literature focused primarily on the most common DCF techniques which are NPV and IRR. These techniques are by far the most widely used and trusted methods of capital budgeting found in business worldwide. Their simplistic make up of using an all encompassing discount rate to account for the present value of future cash flows has made DCF both easy to understand and to implement. Further still, the single metric result gives those who use NPV a simple invest or don't invest decisional criteria. Naturally, however, there are problems with DCF techniques and the assumptions applied to the capital budgeting of investments. Fundamentally, DCF analysis is a static investment tool which poorly represents the risk structures in a dynamic environment and inspires both lazy and passive management styles. Although risk is accounted for through the Weighted Average Cost of Capital (WACC) and the pricing of risks associated with the asset is assessed using a Capital Asset Pricing Model (CAPM), the risk factors are still shallow and unresponsive to sudden change.

Further research was conducted to investigate DCF methods which account for risk such as the Certainty Equivalent (CE) and Risk Adjusted Discount Rate (RADR) methods. Of the two, the CE method is theoretically better as it allows risk to be factored into both future cash flows as well as the discount rate. Sadly, however, the RADR is used most commonly and in essence is a discount rate adjusted form of conventional NPV analysis. With DCF analysis deficient in its ability to account for realistic business flexibility and account for risk, the study investigates the use of ROA techniques, which forms the third and final core topic. Real options analysis is based on financial option pricing theory which was used in the valuing of volatile an uncertain stocks and shares on the stock exchange. The adaptation to real options naturally led to the use of option theory to physical and tangible assets. By using option valuation tools such as Black-Scholes and Binomial lattices, the real option value can be attained for physical asset investments. ROA provides a broad based framework for decision making under uncertainty and is enhanced by the flexibility of future variations. Real options are based on stochastic or random process mathematical variables which present the value of a random system as it evolves. By likening financial option parameters to real, physical assets, the option value inherent in real investments can be found. In addition, risk and uncertainty, which are usually frowned upon in conventional DCF analysis are assigned value through real options.

The study presented agues that real options can be used as a supplementary decision tool to DCF in the capital budgeting of investment decisions. Some real options variables are based on everyday DCF variables and thus exploit the widespread use of DCF methods. ROA also considers its own metrics which enhances the value found in investment options which DCF analysis is unable to account for. In this way, a combined capital budgeting investment tool is created where investments can be evaluated on more than one platform which currently consists of invest, or don't invest NPV criteria. By creating two extra value adding metrics based on real option tools, an active mapping framework is created with six active decisional criteria. Risky investments which hold uncertain future potential can be mapped on the active managerial engaging framework and decisions can be based on two metrics and six varying criteria. Chapter 3 presented next, provides an active mapping investment tool used in the capital budgeting of physical assets within a PAM framework.

Chapter 3

Building an Active Mapping Investment Tool within a Physical Asset Management Framework

This study explores the implementation of a combined Discounted Cash Flow (DCF) and Real Options Analysis (ROA) active mapping tool to supplement the capital budgeting of investments within a Physical Asset Management (PAM) framework. In most organisations the capital budgeting structures and tools used are both stagnant and inflexible in valuing investments. Building on a combined framework theory and on an active mapping tool a more informative capital budgeting tool is outlined in this chapter.

The active mapping framework combines both NPV and Black–Scholes (BS) decision tools to value investments within a PAM framework. The need for more informative capital budgeting techniques in PAM has been highlighted by the inability of organisations to account for risk and flexibility. By focusing on the differences between DCF and real options valued insight can be gained by analysing contrasting features. In order to develop an implementable tool however it is far better to use methods that are recognisable and widespread such as DCF methods. By combining both methods more advanced mathematical ROA tools can be retrofitted to widely used and foundational DCF techniques.

3.1 Overview

The active mapping framework developed in this study is based on the expanded NPV concept of Dai *et al.* (2000) and Tiwana *et al.* (2006) where investment decisions are based on both traditional NPV and ROA methods. This forms the central concept circumscribing the proposed framework and is expressed by Equation 3.1 below.

$$NPV_{\text{active}} = NPV_{\text{passive}} + f(\text{real options value}) \tag{3.1}$$

The step by step guide outlining the active mapping framework is based around Equation 3.1 and is further embodied using Figure 3.1. Step 1 of the framework seeks to evaluate a conventional DCF statement and identify critical investments. By applying a real options paradigm to the cash flow statement, the passive NPV is calculated using the conventional PV criteria. Once the passive NPV has identified strategic investment options, the real options parameters can be established. These real option parameters are likened to financial option parameters where they can be used in Steps 2 and 3. Step 2 calculates the two value adding metrics used for the active mapping tool and actively plots the investment decision. Finally, in Step 3, Black-Scholes is used to price the option value inherent in the investment. With both the real options and passive NPV calculated, Equation 3.1 can be used to determine the active NPV.

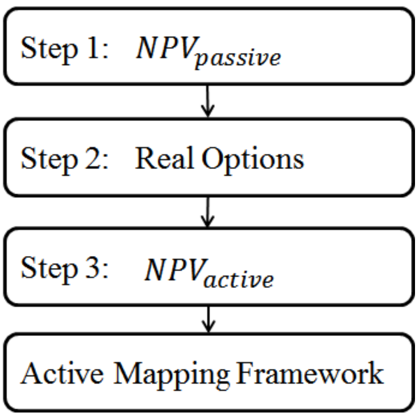

Figure 3.1: Active mapping framework overview

3.2 Active Mapping of a Physical Asset Investment

Consider the case where a company is planning a proposed expansion of their manufacturing division. They are anticipating further investments in large equipment in three years as shown in the discounted cash flow statement presented by Table 3.1 below. The initial investment is quite clearly strategic as it creates an opportunity for future growth, however with the investments needed in year three, executives are unimpressed by the negative NPV and low rate of return with the project currently at $-$R26.86 million.

Table 3.1: DCF projections of a proposed plant expansion (Rand Millions)

Year	0	1	2	3	4	5	6
Cash Flow	10	20	25	40	60	80	90
-Expenses	2	5	6	10	20	25	20
-Capital Expenditure	45	10	8	110	25	15	20
x Discount factor(15%)	1	0.87	0.76	0.66	0.57	0.50	0.43
= PV (each year)	(37)	4.35	8.32	(52.60)	8.58	19.89	21.62
NPV(sum of years)	**(26.86)**						

According to the information provided by the company money can be leveraged against risk free government bonds at a rate (r_f) of 8%. The risk of investing in the proposed expansion project has a volatility (σ) of around 40%. As pointed out earlier the company is looking to either defer or abandon the project based on a timespan (t) of between three and five years. Note that the risk-adjusted discount rate of 15% is calculated through the Weighted Average Cost of Capital (WACC) technique and is applied in the DCF calculations.

3.3 Step 1: NPV_{passive}

The first paradigm shift applied to the conventional DCF analysis is the separation of the investment opportunity from the cash flow statement in Table 3.1. Other than the capital expenditures in year zero and year three the capital expenditures appear somewhat constant. In addition, once the two larger capital expenditures are made, the cash flows increase substantially. In this cash flow statement, the R110 million investment in year three is clearly both strategic and influential in the future growth of the company. This can be seen in the dramatic increases in cash flow from year four and onwards compared to the years before.

Table 3.2: DCF projections of a proposed plant expansion (Rand Millions)

Year	0	1	2	3	4	5	6
Cash Flow				40	60	80	90
- Expenses				10	20	25	20
- Capital Expenditure				110	25	15	20
x Discount factor(15%)	1	0.87	0.76	0.66	0.57	0.50	0.43
= PV (each year)				(52.60)	8.58	19.89	21.62
NPV (sum of years)	**(2.52)**						

The passive NPV or NPV_{passive} can be calculated by considering the separation of the investment in year three expressed in Table 3.2. Along with this calculation comes two of the primary metrics used in ROA. These parameters are S and X an they are the linking metrics between an investment opportunity and a financial call option used in the valuation of real options. Equation 3.2 below illustrates the passive NPV analysis as well as the link with real option parameters S and X.

$$NPV_{\text{passive}} = \underbrace{\text{Present Value of Assets}}_{\text{S}} - \underbrace{\text{Required Capital Expenditure}}_{\text{X}} \qquad (3.2)$$

Thus in the case of Table 3.2, NPV_{passive} is calculated by using Equation 3.3.

$$NPV_{\text{passive}} = (8.58 + 19.89 + 21.62) - 52.6 = -\text{R}2.52\,\text{million} \tag{3.3}$$

The NPV in Table 3.1 is highly unfavourable at −R26.86 million. By most DCF standards this investment will be disregarded due to its extremely low rate of return. By simply separating the investment in year three from the remainder of the cash flow statement and evaluating only those parameters associated with the buying of equipment, the NPV scenario improves significantly to −R2.52 million as seen in Table 3.2. The negative NPV_{passive} indicates that there is both high risk as well as a low return on investing in such an expansion. By looking at the parameters, all that is on offer valuing the investment is a standard risk-adjusted discount rate which ultimately provides NPV with two decisions—invest or don't invest.

3.4 Step 2. Real Options

From a real options perspective, the investment is only taking place in year three, thus the investment can be defined as a *deferral option*. The real option parameters are displayed in Table 3.3 and are used in the calculation of the active mapping value adding metrics NPV_{newQ} and C_{v} as well as the Black-Scholes equation.

Having defined all the relevant variables, the first real option calculations presented are the active mapping metrics NPV_{newQ} and C_{v}. Figure 3.2 illustrates which parameters are associated with each equation. The risk free government bond rate r_f is used in this case as a replicating portfolio while the investment is deferred for three years (t). This adds value and is the foundation of the NPV_{newQ} metric. The second value adding metric is the cumulative volatility which consists of a standard deviation or risk variable σ multiplied by the square root of time t.

$$NPV_{\text{newQ}} = S/PV_{\text{invest}}$$

Table 3.3: Real option parameters: Active mapping framework

Investment Opportunity	Call Option	Variable	Value
Present value of cash flows obtained from the investment option	Stock price	S	50.08
Present value of the expenditure required for project expansion	Exercise (Strike) price	X	110
Period that project expansion option is available for	Time to expiration	t	3 years
The South African prevailing bond rate	Risk free rate of return	r_f	8%
Uncertainty in the cash flow generated by the investment option	Volatility of returns	σ	40%

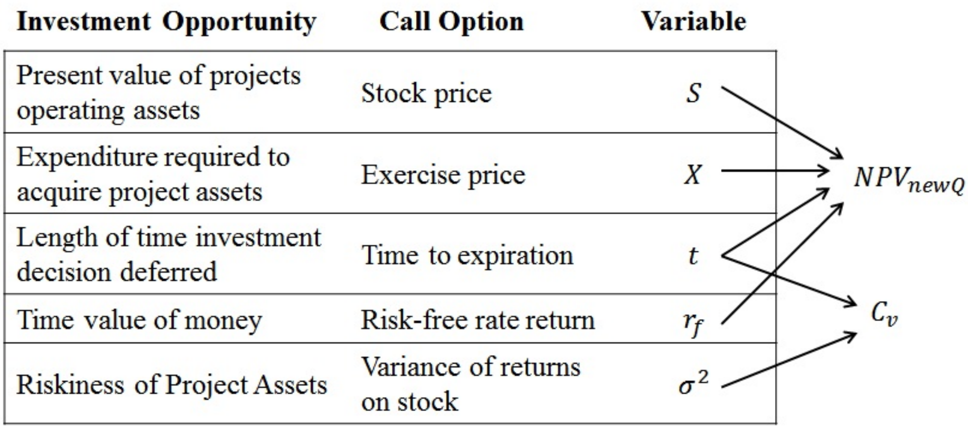

Figure 3.2: Linking option value and investment metrics

Where:

$$PV_{\text{invest}} = X \div (1 + r_f)^t$$

Thus

$$NPV_{\text{newQ}} = \frac{50}{110 \div (1.08)^3} = 0.57$$

The second equation *cumulative volatility* or C_{v} obtains value by attaching some worth to the level of uncertainty in an investment decision.

$$C_{\mathrm{v}} = \sigma\sqrt{t}$$

$$C_{\mathrm{v}} = 0.4 \times \sqrt{3} = 0.693$$

3.5 Step 3: $NPV_{\textbf{active}}$

The final section ties up the active NPV theory by Tiwana *et al.* (2006) which sums the values of a traditional or passive NPV with the real options value of the same investment. In Step one of the proposed framework, NPV_{passive} was calculated using tried and tested conventional methods. The final piece missing is the real option valuation of the proposed investment. This is now calculated using the Black-Scholes option pricing model.

By plugging the relevant parameters from Table 3.3 into the Black-Scholes Equation 3.4 below the desired real option call value for the investment option is obtained.

$$\begin{aligned} \text{BS call value} =& S\Phi\left[\frac{\ln(S/X) + (r_f + \sigma^2/2)t}{\sigma\sqrt{t}}\right] - \\ & Xe^{-r_f(t)}\Phi\left[\frac{\ln(S/X) + (r_f - \sigma^2/2)t}{\sigma\sqrt{t}}\right] \\ =& 35\Phi\left[\frac{\ln(50/120) + (0.08 + 0.4^2/2)3}{0.4\sqrt{3}}\right] - \\ & 110e^{-0.08(3)}\Phi\left[\frac{\ln(50/110) + (0.08 - 0.4^2/2)3}{0.4\sqrt{3}}\right] \\ =& \text{R5.39 million} \end{aligned} \tag{3.4}$$

With the real options value of the investment known, the active NPV can now be calculated.

$$\begin{aligned} NPV_{\text{active}} &= NPV_{\text{passive}} + f(\text{real options value}) \\ &= -2.52 + 5.39 \\ &= \text{R}2.87\,\text{million} \end{aligned}$$

While the active NPV looks at the contrast in both the conventional NPV value and the real options value, the active mapping tool can add perspective. Perspective comes in the form of various decisional criteria, six in total, which provide guidance to an otherwise irrelevant real option value. In addition the active map hopes to influence a more engaged and active participation in the movements of the investment as variables can be tweaked, modified or experimented upon to understand the potential risks, returns and factors influencing the investment.

3.6 Active Mapping Framework

Now that the added value parameters have been calculated the investment can be plotted on the active and visual mapping framework instead of the traditional two decisional "invest" or "don't invest" criteria based on a single NPV metric. The active mapping framework can now be used to assess the value of the investment based on six decisional sections as well as two metrics, NPV_{newQ} and C_{v}. Figure 3.3 below illustrates an option map, with six varying option spaces where the real investment investigated is plotted. Additionally Table 3.4 below presents a results overview of the investment along each step towards the active mapping framework.

Using Figure 3.3, the active mapping framework indicates that the investment should be considered at a later stage with it being in the "maybe later" section. On the horizontal axis, the investment is measured using a value-to-cost ratio called NPV_{newQ}. Using NPV_{newQ} the break even point is at one, so currently the investment shows little promise with a poor value-to-cost ratio of 0.57. In most DCF analysis, this is where the final investment decision is made.

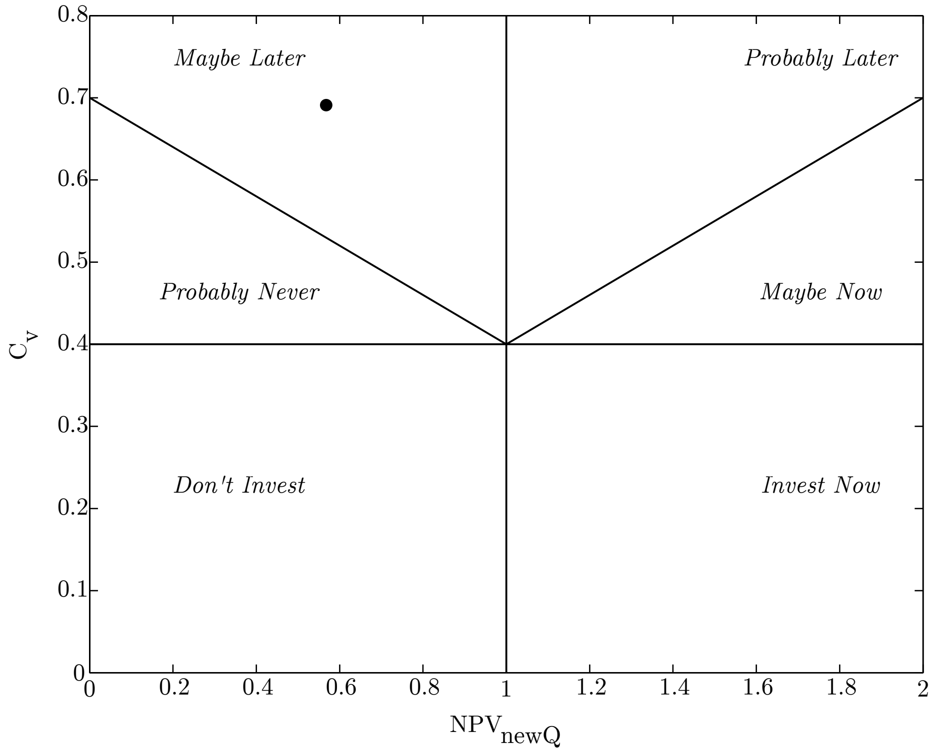

Figure 3.3: Active mapping of an expansion investment option

Conversely, by using real options, the vertical axis presents a different metric which assigns value to the amount of uncertainty in the expansion investment. The cumulative volatility or C_v was calculated as 0.69 and according to the active map layout is a high value. Although the C_v is high, it essentially saves the investment option as it places it in the "maybe later" section. With a lower C_v value, the investment would land up in the "probably never" or worse still "invest never" section, but due to the uncertainty of the expansion, real options finds some potential in the investment. The investment can still be considered in terms of the active mapping framework with a real option value of R3.39 million and an active NPV of R2.87 million. Due to the high uncertainty prevalent in the investment, conditions can still change driving the investment into more favourable circumstances. Should the manufacturing company have the patience, the investment should be watched and actively managed instead of blindly disregarded.

Table 3.4: Data overview of mapping framework

Data Analysis	Variable	Expansion Project
Step 1	$NPV_{\mathbf{passive}}$	(2.52)
Step 2	S	50.08
	X	110
	r_f	8%
	t	3 years
	σ	0.4
	$NPV_{\mathbf{newQ}}$	0.57
	$C_{\mathbf{v}}$	0.69
Step 3	**BS Option Value**	3.39
	$NPV_{\mathbf{active}}$	2.87

3.6.1 Scenario Analysis

The real advantage of using the active mapping tool, is the ability to map various scenarios in order to track, compare and understand investments and how their future unfolds. This section aims to present a scenario analysis which can plot various investment paths, within the active mapping space. In much the same way a *sensitivity analysis* is performed within capital budgeting structures, the scenario analysis seeks to investigate how investments *move* within the option space. A significant part of investment decision making relies on future simulations based on irregular financial conditions. By building in a scenario analysis, the active mapping tool can actively track the path investments could follow, based on predefined conditions. By using the mapping space, plotting different scenarios gives an illustrative representation of the investment against its own financial strength. By changing parameters, the investments growth or decline can be actively tracked and strategically aligned with business goals.

Table 3.5 given below represents the parameter definitions for the option mapping scenario analysis to be carried out. The *Base Case* is the standard initial investment presented. From the base case two other scenarios are tested. They are Case 1 and Case 2 scenarios. Each scenario is now discussed, giving light to the parameter changes chosen.

Table 3.5: Scenario analysis for option mapping space

Variables	**Base Case**	**Case 1**	**Case 2**
S	s	s	$s \times 1.7$
X	x	x	x
r_f	r_f	r_f	r_f
T	t	t	$t - 1$
σ	σ	$\sigma - 10\%$	$\sigma - 10\%$

Case 1 This case illustrates the negative nature of a lower volatility (σ) value. Real options acquire value in the uncertainty of investment opportunities through the cumulative volatility variable and option pricing models.

Case 2 This scenario stages more complex variations. It increases the S value but also has a reduced volatility (σ) and time (t). The assumption is that the investment is in a more favourable value-to-cost zone and with increased confidence in the investment, the risk profile has been lowered. In addition the deferral period t has been reduced by one year.

Using the two added scenarios and working through the necessary steps required, the resulting variables and parameters are portrayed in Table 3.6. Furthermore, the active mapping framework plots each scenario in Figure 3.4 to illustrate the subsequent variations.

Looking at the results in both Table 3.6 and the active mapping plots of each investment in Figure 3.4, there are a number of observations made. Each scenario is discussed to give a better understanding of the results as well as the benefit of using an active mapping framework.

Table 3.6: Active mapping scenario parameters

Variable	**Base Case**	**Case 1**	**Case 2**
S	50.1	50.1	85.1
X	110	110	110
r_f	0.08	0.08	0.08
T	3	3	2
σ	0.4	0.3	0.3
Real option values			
$NPV_{\mathbf{newQ}}$	0.57	0.57	0.9
$C_{\mathbf{v}}$	0.69	0.52	0.42
BS option value	5.39	2.52	11.10
$NPV_{\mathbf{active}}$	2.87	0	8.58

Case 1

The fist scenario was used to illustrate the effect of a lower volatility metric. Although the volatility of the investment was reduced by only 10%, the Black–Scholes (BS) option value dropped from the base case of R5.39 million to R2.52 million and the active mapping criteria became less favourable moving into the "probably never" quadrant. Real options assign value to investments which hold some measure of uncertainty as it believes that with uncertainty arises the possibility of future potential. This is representative of investments in new market sectors such as information technology or in the strategic movement of companies into niche product markets. In these investment cases, there is often a great deal of uncertainty and conventional DCF analysis struggles to identify the value inherent in indefinite investments. Case 1 was chosen to illustrate the value assigned to volatility in a real options framework.

Case 2

Case 2 was adapted quite significantly from the Base Case. Each adaptation had a unique effect on the overall option value of the scenario as well as its placing on the active map. The R11.10 million BS option value for Case 2 was far

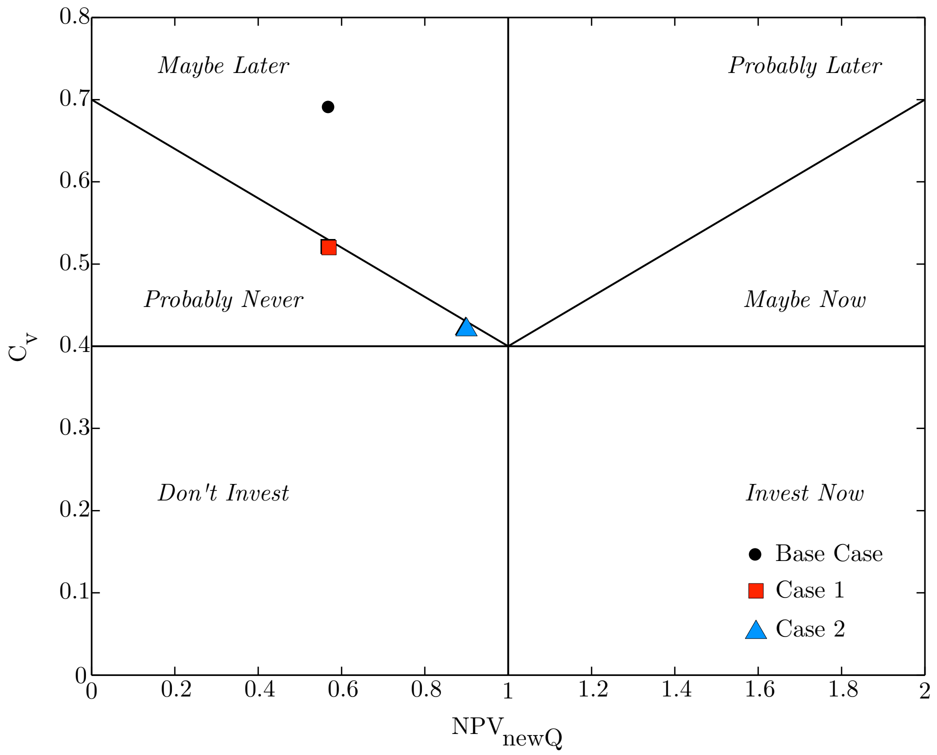

Figure 3.4: Active mapping tool scenario analysis

higher than the Base Case, primarily due to the increased S or present value of future cash flows. The high option value and subsequent active NPV make this investment look very attractive but the active map presents an unobstructed perception of the scenario. While the value-to-cost or NPV_{newQ} metric has increased with S, the cumulative volatility has suffered with a lowered time period and a lower standard deviation.

Although the value-to-cost metric has presented more favourable results, the option metrics have calculated that with little uncertainty and time remaining, not much more will change regarding the outcome of the investment. For this reason, the active mapping framework views this scenario as a "probably never" investment. The time to defer the project has reduced, few parameters can change the outlook of the investment and with a low uncertainty metric, the investment is now more assured of its investment future, which is not particularly good. This example highlights the danger in simply accepting investments with a high option value. The manipulation of parameters can instigate a high option value, but by using a visual active mapping tool, the investments path can be better understood and all variables can be accounted for.

3.7 Summary

Following on from the combined DCF and ROA framework presented in Chapter 2, this chapter outlines a framework to implement an active mapping framework in supplementing conventional DCF analysis. DCF methods establish the primary base of capital budgeting by discounting the risk associated with future cash flows based on an investments cost of capital. By using strong structural boundaries and limiting assumptions DCF analysis techniques are easily implemented which has fuelled both their widespread use and their acceptance as a principle capital budgeting measure in most companies. Principally however, DCF methods do not account for the flexibility that is innate in a lively business environment, nor does it take into consideration the value associated with uncertainty and volatility. ROA uses option pricing metrics to account for the uncertainty which comes with the capital budgeting of real, physical asset based investments.

By using existing DCF structures which are common in most organisations and supplementing them with ROA, a combined framework is created which exploits the strengths of both capital budgeting techniques. While most investment decisions fall victim to a one number syndrome with gauges such as NPV, the active mapping tool plots investments within a visual option space with various decisional criteria, prompting a more active management approach. This chapter outlines a framework where conventional DCF based investment decisions can be analysed using both ROA and an active mapping tool. By using real option valuation techniques and the Black-Scholes option pricing method, physical asset based investments can now account for both uncertain and flexible investment influences. The framework is presented by using an example of an expansion project where there is a possibility of implementing a deferment option. The results are presented in Table 3.7 with a broad based summary of the outlined steps and results to follow.

The initial NPV of the project presented highly unfavourable results with a value of −R26.86 million and in most cases the project would be rejected due to its low return. By isolating the investment in Step 1, and taking into account only those cash flows directly related to the expansion investment, the passive NPV or NPV_{passive} was improved to only −R2.52 million. These however, are still only single values, with little perspective or insight. The investment criteria is still unfavourable and more information is needed to make a decision. The primary real options analysis begins at Step 2 where the real option parameters are defined and the two value adding metrics NPV_{newQ} and C_{v} are calculated.

Table 3.7: Final results overview of an active mapping framework (Rand Million)

Data Analysis	Variable	Expansion Project
DCF	**NPV**	(26.86)
Step 1	$NPV_{\textbf{passive}}$	(2.52)
Step 2	$NPV_{\textbf{newQ}}$	0.57
	$C_{\textbf{v}}$	0.69
Step 3	**BS option value**	3.39
	$NPV_{\textbf{active}}$	2.87

Three of the five real options parameters are taken directly from the original NPV analysis: these are S, X and the time period until the investment option is exercised t. The final two real options parameters are generally more scarce and are infrequently used in conventional DCF analysis, they are the volatility (σ) and the risk-free rate (r_f). The volatility metric is usually presented from either historical data, an educated guess or even through some form of simulation. The volatility measure is also the standard deviation associated with the expansion investment. It represents the uncertainty associated with the expansion of the project. The risk-free rate can be determined from either a savings plan or more commonly, risk-free government bonds. This is used to hedge the deferment option against inflation and earn interest on the investment over the time period t until the investment costs are incurred. Using these variables the value adding metrics are calculated and can be plotted on an active mapping tool such as Figure 3.3.

The final step, Step 3, calculates the Black-Scholes option value along with the active NPV or NPV_{active}. The active NPV represents the total combined value of the investment based on both DCF and real option valuations. While the NPV analysis finds little value in the investment based on slow initial cash flow, high capital expenditure and an all encompassing discount rate of 15%. The ROA was able to assign value to both the uncertainty of the project using the σ value, and managerial flexibility by deferring the investment option for three years at a risk-free rate. The active NPV result of R2.87 million presents a more favourable investment criteria. However, it still only presents a blind investment decision based on one metric. This is where the active mapping framework exhibits its potential.

The active mapping framework places the investment decision within the "maybe later" option section. Rightly so as the investment shows a weak value-to-cost ratio on the NPV_{newQ} axis, which is representative of a conventional NPV type analysis. The difference in using the active mapping tool however, is in the value assigned to the cumulative volatility of the expansion project. With high uncertainty in the future potential of the project, the active mapping tool does not disregard the investment. In many business decisions, high risk can influence high reward. While this is not particularly the case in this investment, the mapping tool does not disregard the future possibility.

To further enhance the aptitude of the active mapping tool, a scenario analysis is employed, where the investment can be plotted against various future possibilities. Within a business environment, variables can be manipulated to tailor specific scenarios much like that of a sensitivity analysis. In this framework two scenarios where implemented and were expressed in Figure 3.4. The first scenario, Case 1, demonstrated the value attributed to higher volatility. Case 2, was interesting as it illustrated the problem of blindly accepting a high option value. While the option value and active NPV indicate high gains, the active mapping framework exhibited otherwise, indicating the weak potential of the investment.

The active mapping framework is presented in Chapter 3 using a hypothetical example. In order to test its potential and usefulness in supplementing DCF capital budgeting techniques the framework is implemented in a case study presented next in Chapter 4.

Chapter 4

Case Study

4.1 Background

This case study outlines the capital budgeting and capital expenditure required in the opening of a new Anglo Platinum mine in the Mpumalanga province. Critically important to the operation is the transport of raw materials from mining operations to the concentrator plant. The study compares the capital budgeting difference in using either a conveyor system or building a new road in transporting raw materials. The concentrator section is where raw materials are processed to create an end product. Based on the layout of the plant, raw materials must be transported economically, safely and timely. The transport of raw materials is critical to the revenue generated by Anglo Platinum's operations.

4.1.1 The Problem

Anglo Platinum has two potentially viable raw material transport operations under negotiation. The first option is to build a new road which will run parallel to the provincial road currently in use. The road currently used, runs through a large community and according to risk assessment reports has a high safety risk. The building of a new private Anglo Platinum road will reduce the safety risk as it will be fenced off and restricted for Anglo use only. The second option explores the building of an overland conveyor to transport raw material from mine to concentrator. The conveyor has a far lower safety risk however its capital expenditure is almost double that of the new road investment. Both investments are unfavourable at present according to conventional NPV analysis.

Anglo Platinum is exceedingly focused on completing the proposed mining operation and adamant in building either one of the investments. Due to the low NPV presented by either investment Anglo Platinum are interested in evaluating the unfavourable investment according to an alternative framework, considering more than just DCF techniques. This created an opportunity to integrate a supplementary real options capital budgeting tool into a highly detailed DCF forecast. In addition, real options has the added benefit of evaluating the value attached to risk assessments provided by Anglo Platinum, which currently does not form part of their capital budget.

4.1.2 Case Study Aim

The aim of the case study is to validate the active mapping framework outlined in Chapter 3 by using an investment in a PAM framework presented by Anglo Platinum. By using real options techniques the investments are evaluated on both conventional NPV analysis as well as the on the Anglo Platinum risk and impact assessment. The investments in question are essentially analysed using real option valuation metrics and a visual active mapping option tool. By implementing a combined real options and DCF capital budgeting analysis, the case study aims to provide a more informed decision making tool. Both investments provide unfavourable DCF conditions based on their financial forecasts. However, by gauging the influence of each investments innate real option value, more insight is presented to an otherwise inauspicious NPV value.

4.1.3 Chapter Overview

The sections to follow outline key factors influencing the capital budgeting of either building a new road or an large conveyor spanning the distance from mine to concentrator. Besides key financial and economic factors, environmental impact, safety, and the surrounding community are all pivotal to the final decision. The case study thus contains not only traditional DCF spreadsheet material, but also an all encompassing risk assessment of the plant, project, environment and the surrounding community. In the subsequent section titled Variables and Assumptions, all relevant data used in the analysis is made evident.

To follow the variables and assumptions section is the Data Analysis section where three primary steps are described in conjunction with the Chapter 3 structure. The three steps incorporate the passive NPV, the real options analysis and finally the active NPV. Using this analysis the active mapping framework is generated to visually illustrate the current investment potential of each option. Furthermore a multiple scenario analysis is plotted on the active mapping framework. This gives a visual representation of the investments in question, along with possible financial scenarios and strategic optional insight.

4.2 Variables and Assumptions

Before a real options analysis can take place two new variables rarely used in conventional DCF analysis are defined. The first variable is the standard deviation or σ while the latter is a risk–free rate denoted as r_f. Due to their limited use in conventional DCF and NPV analysis the variables have been chosen using industry specific assumptions directly related to the case study presented. Standard deviation (σ) is used in the calculation of cumulative volatility and the Black–Scholes European call option value. The risk–free rate (r_f) is taken from government bond rates and used as a replicating investment profile.

4.2.1 Risk Free Rate: RSA Retail Savings Bonds

Conventional NPV neglects value associated with deferring investments, assuming investment decisions cannot be rescheduled. Conversely, option pricing theory accepts the deferral and in addition appraises the investment deferral. This value adding metric is NPV_{newQ} and it allows an investment to earn interest through a replicating portfolio, while the investment decision is deferred. The replicating, risk–fee (r_f) portfolio in this case, are Republic of South Africa (RSA) Retail Savings Bonds. Luehrman (1998a) explains if just enough money is placed in the bank that, when the time comes to invest the initial amount plus the interest earned, it will be sufficient in funding the required expenditure.

What are RSA Retail Saving Bonds? Essentially, they are financial instruments in the capital and money market issued by the National Treasury to finance the governments budget deficit. Investors, banks, brokers, pension funds, insurance companies, foreign investors and individuals alike buy these bonds in hedging money invested against inflation. Although percentage returns are not significant, the RSA retail bonds are backed by government and offer more reliable, "risk–free" returns on money invested. Earnings are considerably less than on other investment platforms, the risk however is significantly less. Ultimately offering a "safer" replicating portfolio in earning interest on money otherwise falling victim to inflation over time.

There are two series of RSA Retail Savings Bonds on issue, namely RSA Fixed retail savings bonds with either two, three or five year maturities and RSA Inflation Linked retail savings bonds with three, five and ten year maturities. Below Table 4.1 defines the respective bond options, along with relevant interest rates earned per option.

Table 4.1: RSA Retail savings bond rates

Bond Type	**Period** (years)	% **Rate**
Fixed Rates	2	6.75
	3	7
	5	7.5
Inflation Linked Rates	3	1
	5	1.25
	10	2.25

Source: Bonds (2012)

Based on the presumption of a South African inflation rate stabilising around an average of 6.28% by Inflation.eu (2012), which is illustrated in Figure 4.1 below, a bond type can be chosen. In sufficiently hedging a replicating portfolio for the prescribed physical asset investment against the assumed inflation rate, the *inflation linked* rates are implemented. This portfolio hedges the rate for a period chosen above that of inflation, i.e for a five year investment period the inflation linked retail bond earns interest at a rate of 7.53% (6.28% + 1.25%).

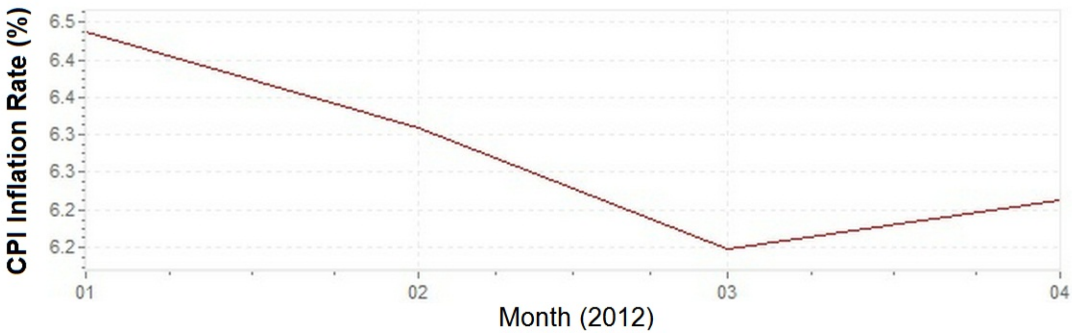

Figure 4.1: CPI inflation chart: South Africa 2012

Adapted from Inflation.eu (2012)

4.2.2 Volatility

The variable used in the option mapping framework that is furthest removed from conventional DCF analysis is the standard deviation (σ). Unfortunately σ can not be found on financial spreadsheets and standard deviation will differ greatly within various asset classes and unpredictable market conditions. There are however three principle approaches which can be used in finding a reasonable estimate for σ which are: an educated guess, data gathering and finally, simulation. The Anglo Platinum case study presents both historical data and sources of industry specific experience leaving simulation unnecessary.

Anglo Platinum evaluates risk on a host of different levels to determine critical deficiencies affecting investments. However, there are no measures which can relate the value of the risk against a financial analysis, such as NPV. The project risk manager assembles a risk assessment of both the road and the conveyor options considered. This section first identifies the most prevalent and critical risks associated with each option. From this point, option valuation tools can attach value to the risks presented in each case.

Risk Assessment Matrix

The following section represents the most critical risks associated with either the conveyor or road options. The risks are rated according to a matrix which is demonstrated by Figure 4.2 and measures risk along two axes. The horizontal axis evaluates the consequence of the risk on a scale of one to five, with one being *insignificant* and five being *major*. The vertical axis rates the frequency or likelihood of the risk happening, again from a scale of one to five, with one being *rare* and five being *most certain* of the risk taking place. In conclusion a 5×5 matrix is created and a percentage risk is attached to each element within the matrix according to the number assigned risk value.

Consequence Type	1-Insignificant	2-Minor	3-Moderate	4-High	5-Major
Likelihood	**Risk Rating**				
5-Almost Certain	11 Medium	16 Significant	20 Significant	23 High	25 High
4-Likely	7 Medium	12 Medium	17 Significant	21 High	24 High
3-Possible	4 Low	8 Medium	13 Significant	18 Significant	22 High
2-Unlikely	2 Low	5 Low	9 Medium	14 Significant	19 Significant
1-Rare	1 Low	3 Low	6 Medium	10 Medium	15 Significant

Figure 4.2: 5×5 Risk assessment matrix (Anglo Platinum risk assessment data)

Table 4.2 lists the most important project risks for both the road and conveyor options. In understanding the risk value given, an illustration of the risk matrix is provided by Figure 4.2 adding perspective to the severity of the risk. A risk percentage guide shown by Table 4.3 correlates with Figure 4.2 and Table 4.2. The standard deviation (σ) is deduced from Table 4.3. Seemingly limited, the percentage risk estimate will provide sufficient financial insight and added value using the cumulative volatility metric.

Table 4.2: Comparative risk assessment of a public road and conveyor system

Risk Name	Risk Description	Conveyor Risk Rating	Road Risk Rating
EIA	Environmental Effect	13	13
Road Accidents	Road accidents while transporting materials on public roads	4	18
Community Interaction	Effect of project on surrounding community	12	18
CAPEX	Higher than budgeted Capital Expenditure	17	12
Safety	Overall safety rating for surrounding community and employees	14	20

Table 4.3: Risk rating as a percentage likelihood

Risk Rating	Risk Level	Risk %
1-5	Low	0-25
6-12	Medium	26-50
13-20	Significant	51-75
21-25	High	76-100

The original risk assessment report provided by Anglo Platinum identifies an extensive range of risks. Risk is extremely difficult to quantify, especially when a diverse range of varying risks are presented. Table 4.2 represents the most critical risks identified in the case study as Anglo Platinum view safety as a primary concern in any operation undertaken. Table 4.2 presents (except CAPEX) the risks associated with the environment and surrounding community. In valuing risks associated within the case study, the *safety* figure presented in Table 4.2 is used.

Quantifying risk to estimate cumulative volatility

The option pricing variable least found in DCF analysis is the estimation of variance (σ^2) or the standard deviation (σ). It is difficult to quantify risk and even more so to find a single risk variable which accounts for all possible scenarios. In many cases risk assessments are provided but there are few tools relating the risk to the financial analysis or conventional DCF and NPV decision making criteria.

The risk profile used in the case study is the overall *safety* risk assessment. Safety is identified as Anglo Platinum's primary concern rendering it the real option risk valuation parameter. The difficulty now however, lies in the definition of the *safety* risk, in terms of *financial* risk. Safety risk is then in principle the value adding real option metric associated with cumulative volatility. In order to quantify safety risk in terms of financial risk, two assumptions are defined:

Assumption 1 The higher the risk, the higher the option value

Assumption 2 Safety risk is inversely proportional to financial risk

The first assumption relates directly to option value theory, which assumes high risk equals high reward translating to a high option value. The second assumption draws a relationship between safety risk and financial risk. Consider the case where an investment has a high safety risk, this impacts negatively on the company. Thus a high safety risk can be seen as a high financial risk. In essence, a high safety risk means a high financial risk and thus according to option–pricing models a lower standard deviation (σ) is needed.

Consider the example presented to illustrate the assumptions just made. Imagine an investment has a safety risk of 80%, thus the standard deviation (σ) value is 0.8. A high safety risk translates to a high financial risk. High financial risk is not a favourable investment condition thus high financial risk equates to an unfavourable option value. The lower the standard deviation, the lower the option value. This aligns with *Assumption 1.* Assuming 100% is the highest risk profile, then the financial risk can be calculated as 20% (100% − 80%), this is in direct relation to *Assumption 2.* Thus, the standard deviation of the financial risk is seen as 0.2. Essentially, the safety risk is inversely proportional to the financial risk in terms of standard deviation (σ)

when relating it to option–pricing theory.

By using the risk assessment data provided in Table 4.2 and Table 4.3 the case study method exhibited can be used in attaining the desired standard deviation (σ) value.

4.3 Data Analysis

The section unveils the data analysis of the new road and the conveyor investments. The data presented is in the form of conventional forecast cash flow statements provided by Anglo Platinum. The analysis presents results of the case study based on the active mapping framework described in Chapter 3.

Following the prescribed framework, the standard or *passive* NPV is worked out first using data from Anglo Platinum regarding the investment decision. Step 2 dissects the initial NPV calculations to determine where real options can be applied. Step 3 combines both passive and real option valuation tools to create an active NPV. The viability and validity of the *active* NPV value is then scrutinized through the use of the active mapping tool. Here the cumulative volatility (C_v) and value–to–cost metric (NPV_{newQ}) are used to place the investment within a visual active mapping space.

4.3.1 DCF Analysis: Anglo Platinum

This section provides the cash flow statements used in the capital budgeting of investments proposed. Included in the predicted cash flows are revenues generated, working costs as well as capital expenditure. The discount rate used is an industry standard used in the capital budgeting of new or *greenfield* projects as they are referred to in industry. The rate of 12.5% is based on company specific simulations which take into account inflation, the Weighted Average Cost of Capital (WACC) and even the fluctuation in predicted material (Platinum) prices. In most operations the 12.5% discount rate is used and once projects have proven fruitful and the investment risk has reduced, the project is then classified as a *brownfield* project and the discount rate is reduced to 11.5%.

Conventionally the capital budgeting of a mining operation covers the life of mining operations which can be over 60 years in some cases. In order to better illustrate the concept of the study, a time frame of ten years has been used. It provides enough information as well as flexibility to make strategic decisions over a longer term. In addition, the smaller data range makes it far easier to point out important concepts without presenting a daunting spreadsheet or large, unrealistic time spans.

New Road Investment

Table 4.4 provides the predicted cash flow statement for the building of a new road investment. The cash flow statement has been reduced to present only the most important financial aspects related to the investment decision. The *revenues* earned through the investment decision are based on Anglo Platinum's simulated forecast of future revenues. The *working costs* as well as *capital expenditure* are based on similar projects, historical data and simulated scenarios.

It is important to note the absent revenue streams from 2011 to 2015. This is due to the initial research and infrastructure development which form the foundations of the project. Before any material can be mined, or even transported, Anglo Platinum must set up all preliminary operations, protocols and procedures. Although revenue has not yet been generated, substantial working costs and capital expenditure is required to set up preliminary operations. To give a better perception of the cash flow statement a graphical representation is presented by Figure 4.3. The bar graph compares the revenue, working costs, capital expenditure and yearly present values to expose the new road investment structure.

In the early investment phase, high capital expenditure, slowly increasing working costs and no revenue streams contribute to a negative yearly *present value*. This means that before the new road capital expenditure is exercised in year 2014 and 2015 the investment is running at a loss. From this point however, having acquired and created the new road, revenues increase rapidly. With the steady increase in operations, revenues rise dramatically and capital expenditure tapers off. With operations and production increasing, revenue increases and so too do the working costs. Working costs increase with rev-

Table 4.4: Predicted cash flow statement for the building of a new road (Rand Millions)

Year	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Revenue	0	0	0	0	0	1617.2	2842.3	3415.9	4160.3	6618.7	6113.8
Working Costs	0	307.2	457.3	828.5	1125.7	2058.5	2489.4	2611	2956.6	3094	3142.5
Capital Expenditure	0	772.6	747	1448.1	1976	1194.1	846.4	789.5	706.8	326.2	355.9
Discount Factor (12.5%)	1	0.88	0.79	0.7	0.62	0.55	0.49	0.44	0.39	0.35	0.31
Present Value	0	(959.8)	(951.5)	(1598.9)	(1936.4)	(907.6)	(243.4)	6.7	193.7	1108	805.4
NPV	(4483.7)										

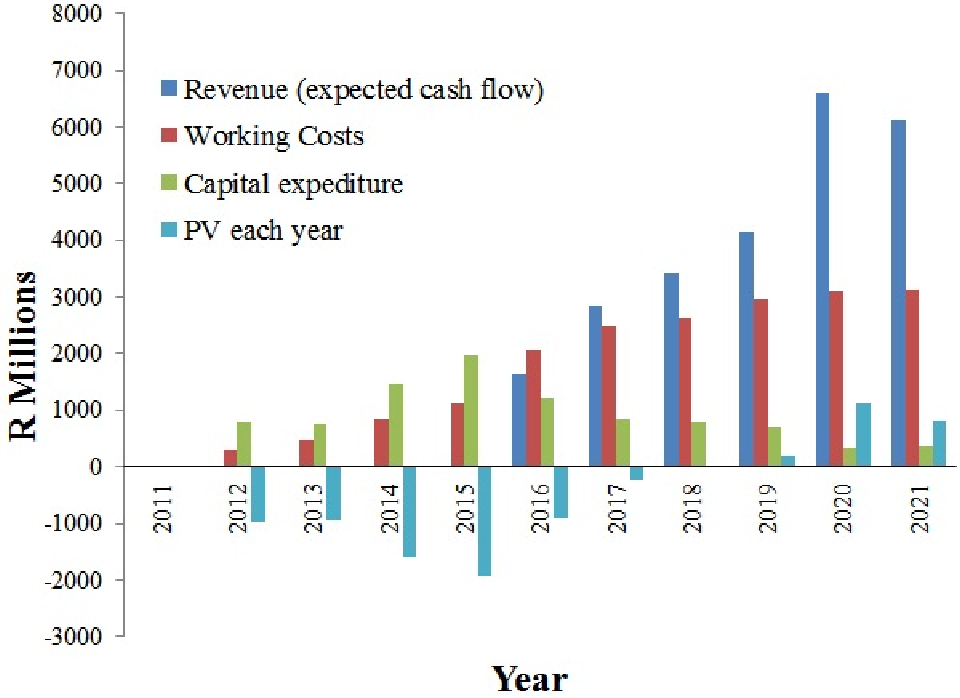

Figure 4.3: Bar chart illustrating forecast cash flow: New Road investment

enue as would be expected, nevertheless by 2019 working costs level out. With increasing revenues and steadying costs, yearly *present value* returns increase as seen in years 2020 and 2021. It is felt that in a larger forecast period even larger increases in present value returns will be seen.

The *capital expenditure* required for the physical asset investment is seen in years 2014 and 2015. It is clear that this is both the pivotal and costly new road investment stage. These are significantly higher capital expenditures in comparison to the rest and are key to the success of the mine and the production of raw materials. Once raw materials are securely transported to the concentrator production operations can take place and high revenue is generated.

Overland Conveyor Investment

The second investment option presents the predicted cash flow statement for the overland conveyor seen in Table 4.5. There are few significant changes in the cash flow statement other than the higher *capital expenditure* of the overland conveyor. This is due to a larger infrastructure outlay required for the overland conveyor. The new road runs almost parallel to the existing road so a considerable part of foundational work has been set up. The conveyor system, however, has two slight advantages over the new road investment and they are the *working costs* and regular *capital expenditure* as demonstrated in Figure 4.4.

As noted earlier, the cash flow investment forecast for both investments are very similar. This can be seen with the addition of a bar chart for the conveyor cash flow statement illustrated by Figure 4.4. Although subtle variations are present the primary difference is the capital expenditure of the conveyor which is significantly higher than that of the new road. Also noted are the reduced capital expenditures and working costs occurring after the conveyor investment in years 2014 and 2015. The smaller capital expenditures presented in the cash flow statement are referred to as "stay-in-business" capital expenditure. As the name suggests, this is the capital expenditure required to keep operations running. The lower stay-in-business capital expenditure is as a result of increased confidence in the overland conveyor system as well as higher operational efficiencies. The increased confidence comes from Anglo Platinum's lower safety risk of the conveyor compared the new road. This will be dealt with more comprehensively in the *real options* section to follow.

Although the NPV is negative for both the new road and the overland conveyor investments there is an increasing revenue stream and only modest fluctuations in working costs and capital expenditure from 2017. This is typical for such operations as large capital expenditure makes way for future growth opportunities. Should the revenue stream continue to grow consistently, the NPV will become more favourable with time. However, the case study requires supplementary motivation in valuing the investment as currently the unfavourable NPV paints a dejected picture. The section to follow assesses the predicted cash flow using option thinking and applying relevant option valuation tools.

Table 4.5: Predicted cash flow statement for the building of a new overland conveyor (Rand Millions)

Year	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Revenue	0	0	0	0	0	1778.9	2899.2	3484.2	4243.5	6751	6236.1
Working Costs	0	337.9	503	911.3	1238.3	1871.4	2263	2373.6	2687.8	2812.7	2856.8
Capital Expenditure	0	927.1	896.4	1737.7	3359.2	2029.9	769.5	717.7	642.6	296.6	323.6
Discount Factor (12.5%)	1	0.88	0.79	0.7	0.62	0.55	0.49	0.44	0.39	0.35	0.31
Present Value	0	(1124.5)	(1105.7)	(1860.5)	(2870.2)	(1177.8)	(65.8)	172.2	355.9	1261.7	941.0
NPV	(5473.6)										

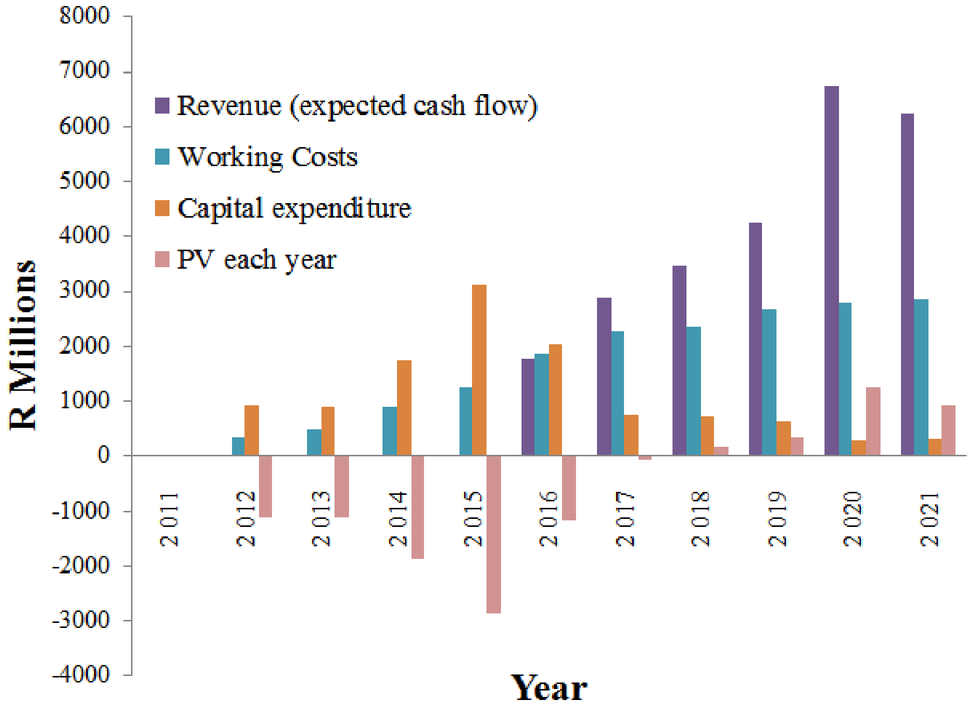

Figure 4.4: Bar chart illustrating forecast cash flow: Conveyor investment

4.3.2 Step 1: NPV_{passive}

Step 1 of the data analysis determines the conventional or passive NPV analysis of the predicted cash flow statements of a new road and an overland conveyor system. Options thinking is applied to the DCF analysis to separate the cash flows directly related to the investment considered. This separation still uses a conventional DCF and NPV analysis and is labelled *Phase 2*.

Pivotal in the Phase 2 separation is the ability to identify the real options that are hidden in conventional DCF analysis. This can be done in a number of ways, but in the case study only one method is used. By simply examining the relevant cash flows, capital expenditures and working costs it is easy to identify patterns and structures directly relevant to the investment in question. Fortunately the DCF analysis provided by Anglo Platinum are similar in key characteristics, however this section will outline prominent features which can distinguish the real options present.

NPV_{passive}: New road

The passive NPV approach begins at Phase 2 of the capital budgeting forecast and is illustrated by Table 4.6. Phase 2 begins with the strategic building of the road which as pointed out begins over 2014 and 2015. This is clearly identified with the capital expenditure bar chart represented by Figure 4.5. From Figure 4.5 the capital expenditure pattern is clearly illustrated as early research, capital development and planning makes way for the large new road investment in year 2015 in Table 4.4. For simplification purposes the two capital expenditures have been added to make one figure seen as R3170 in year 2016 in Table 4.6. This investment is clearly strategic as the capital outlay is far greater than any other and is pivotal to the overall revenue generated from the capital investment.

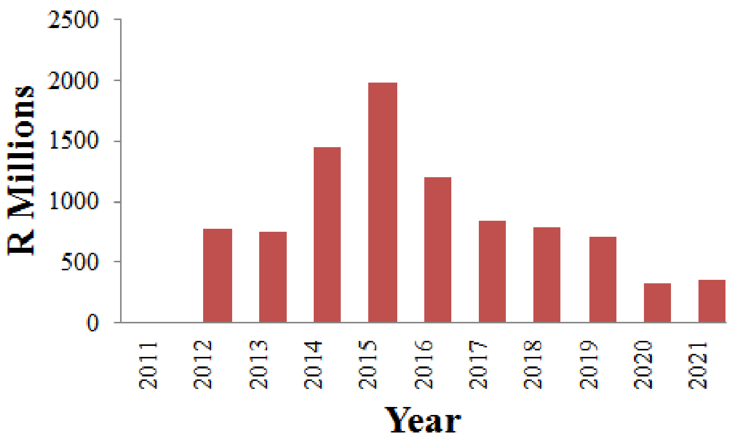

Figure 4.5: Capital expenditure pattern: New road

By isolating Phase 2 from the original cash flow statement (Table 4.4) the initial capital outlay costs and expenditures from 2011 to 2015 are ignored and only the effect of the large capital investment in 2016 is analysed. As seen by the resultant passive NPV (NPV_{passive}) of $-$R133.63 million, the result is already more favourable than the original NPV value of $-$R4483.7 million. The result is based on the exact same DCF and NPV techniques, the difference lies in purely representing the investment in question and challenging a conventional capital budgeting mindset. Figure 4.6 below shows the effect of valuing the new road investment from a real option passive NPV perspective. In this case the factors directly affecting the physical asset are considered. This shows

Table 4.6: Phase 2: Predicted cash flow statement for the building of a new road (Rand Millions)

Year	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Revenue	0	0	0	0	0	1617.2	2842.3	3415.9	4160.3	6618.7	6113.8
Working Costs	0	0	0	0	0	2058.5	2489.4	2611	2956.6	3094	3142.5
Capital Expenditure	0	0	0	0	0	3170	846.4	789.5	706.8	326.2	355.9
Discount Factor (12.5%)	1	0.88	0.79	0.7	0.62	0.55	0.49	0.44	0.39	0.35	0.31
Present Value	0	0	0	0	0	(2004.1)	(243.4)	6.7	193.7	1108.1	805.4
NPV_{Passive}	(133.63)										

the resultant revenues, working costs, capital expenditure and most notably the present value returns earned per year. The initial loss presented in Figure 4.6 is far less than in Figure 4.3 and more fundamentally, presents a cash flow forecast directly related to the new road investment.

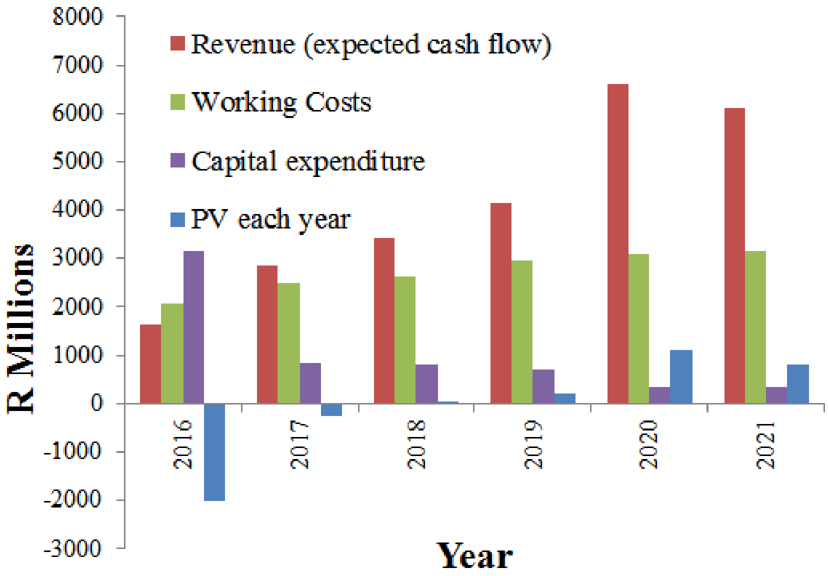

Figure 4.6: Cash flow pattern: New road passive NPV

$NPV_{\textbf{passive}}$: Conveyor

This section outlines the passive NPV cash flow statement in much the same fashion as the *new road* section just presented. Table 4.7 below shows the Phase 2 real option investment analysis of the overland conveyor system. This takes into account the cash flow statement directly related to the investment of the overland conveyor. Again, for simplifying the analysis, the capital expenditures of year 2015 and year 2016 have been combined to create the R5389.1 million figure in year 2016. To recognise where the capital expenditure of the investment occurs Figure 4.7 has been provided. In addition to demonstrating the scenario investment patterns presented by Anglo Platinum's cash flow forecast, it also shows the difference in magnitude of the investments. There is a significant difference in capital expenditures of the road compared to the conveyor and it is the primary factor influencing NPV decisions. By reflecting upon this statement, it is necessary to view what potential lies beyond pure DCF capital budgeting analysis.

The investment still gives a negative NPV, however by applying the passive NPV phase 2 analysis, the NPV has already improved from the original discounted cash flow analysis presented by Table 4.5 with an NPV figure of −R5473.6 million to −R376.9 million. Heavily influenced by DCF capital budgeting techniques, the next section moves into the real options realm. Unconventional value is explored within real options to supplement the investment valuation decisions drawn from DCF capital budgeting NPV and NPV passive metrics discussed.

4.3.3 Step 2: Real Options

New road analysis

In the *Variables and Assumptions* section the risk-free rate determined from inflation linked retail government bonds for a five year investment period is 7.53%. Due to the investment decision period between 2011 and 2016, the decision to invest in the road can, from a real options perspective, be deferred for a time period of five years. The capital expenditure (X) figure used is that presented in year 2016 of R3170 and the *present value of cash flows obtained from the investment option* (S) is calculated as R1870.37 million. Finally the

Table 4.7: Phase 2: Predicted cash flow statement for the building of a new overland conveyor

Year	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Revenue	0	0	0	0	0	1778.9	2899.2	3484.2	4243.5	6751	6236.1
Working Costs	0	0	0	0	0	1871.4	2263	2373.6	2687.8	2812.7	2856.8
Capital Expenditure	0	0	0	0	0	5389.1	769.5	717.7	642.6	296.6	323.6
Discount Factor (12.5%)	1	0.88	0.79	0.7	0.62	0.55	0.49	0.44	0.39	0.35	0.31
Present Value	0	0	0	0	0	(3041.9)	(65.8)	172.2	355.9	1261.7	941
$NPV_{Passive}$	(376.9)										

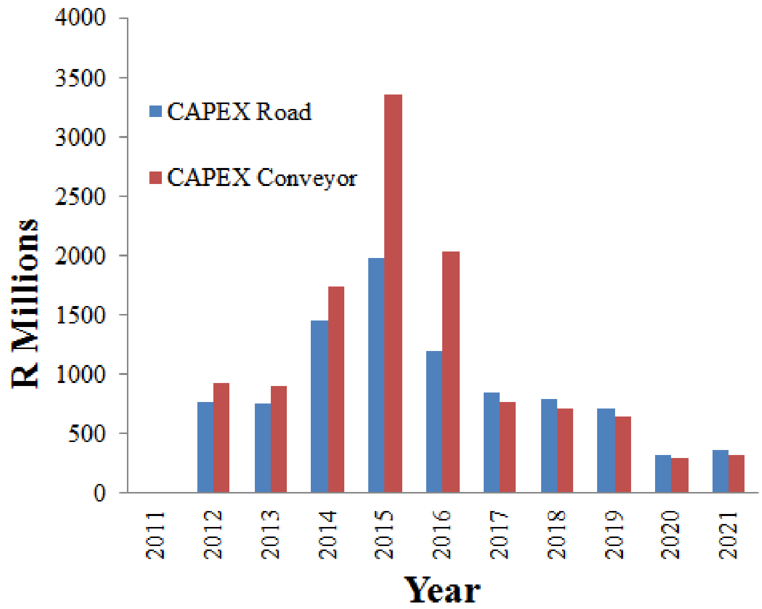

Figure 4.7: Capital expenditure pattern comparison: Conveyor vs New road

standard deviation or σ value is assumed as 25%. The risk rating of 20 is taken from the overall *Safety* risk assessment in Table 4.8.

Consequence Type	1-Insignificant	2-Minor	3-Moderate	4-High	5-Major
Likelihood	**Risk Rating**				
5-Almost Certain	11 Medium	16 Significant	20 Significant e	23 High	25 High
4-Likely	7 Medium	12 Medium d	17 Significant	21 High	24 High
3-Possible	4 Low	8 Medium	13 Significant a	18 Significant b,c	22 High
2-Unlikely	2 Low	5 Low	9 Medium	14 Significant	19 Significant
1-Rare	1 Low	3 Low	6 Medium	10 Medium	15 Significant

Figure 4.8: 5×5 New road risk assessment matrix (AngloAmerican risk assessment data)

By using the risk assessment matrix presented by Figure 4.8 as well as the accompanying risk description in Table 4.8 the standard deviation (σ) is obtained. According to the Anglo Platinum risk assessment the *Safety* risk associated with the building of the new road is rated as a 20 and is very "significant" according to Figure 4.8 where it is represented as letter "e" on the diagram. To give an indication of some of the other risks forming part of the risk assessment letters "a" to "e" have been shown in Figure 4.8 with the associated descriptions in Table 4.8. The safety risk as stated in Table 4.8 accounts for both employee and community interests. It is assumed that a high safety risk rating is clearly a negative aspect. In calculating the value of σ, the higher the risk the higher the financial value thus a high safety risk would reflect as a negative financial value. Thus a 75% health risk (Table 4.2) is treated as a 25% (100%-75%) financial risk. Keeping in mind that the financial option value is linked to the risk or σ variable, thus higher σ values reflect higher option values.

Table 4.8: Risk assessment of a new road

Letter	Risk Name	Risk Description	Road Risk Rating
a	EIA	Environmental Effect	13
b	Road Accidents	Road accidents while transporting materials on public roads	18
c	Community Interaction	Effect of project on surrounding community	18
d	CAPEX	Higher than budgeted Capital Expenditure	12
e	Safety	Overall safety rating for surrounding community and employees	20

Table 4.9 gives a detailed summary of the parameters used in the real option valuation process. By applying these parameters to the data provided by Anglo Platinum; the real option valuation parameters can now be calculated. The three parameters calculated are the *cumulative volatility* (C_{v}), the *new NPV metric* (NPV_{newQ}) and the Black–Scholes option value. Although the

Black–Scholes value is the overall real option value used, the other two parameters use exactly the same information but illustrate a different perspective of the investment when combined with the active mapping tool.

Table 4.9: Option-value-metrics for new road investment

Investment Opportunity	**Call Option**	**Variable**	**Value**
Present Value of cash flows obtained from the investment option	Stock price	S	1870.37
Present value of the expenditure required for project expansion	Exercise (Strike) price	X	3170
Period that project expansion option is available for	Time to expiration	t	5 years
The South African prevailing bond rate	Risk free rate of return	r_f	7.53%
Uncertainty in the cash flow generated by the investment option	Volatility of returns	σ	25%

The two *value adding equations* are now calculated based on their respective formulas combined with the variables in Table 4.9. The first equation addresses the value added NPV_{newQ} which assumes money is invested in risk-free government bonds until the time comes to invest. In this way interest is earned on the money while the investment decision is deferred.

$$NPV_{\text{newQ}} = S/PV_{\text{invest}}$$

Where

$$PV_{\text{invest}} = X \div (1 + r_f)^t$$

Thus

$$NPV_{\text{newQ}} = \frac{1870.37}{3170 \div (1.0753)^5} = 0.85 \tag{4.1}$$

The second equation *cumulative volatility* or C_{v} obtains value by attaching some worth to the level of uncertainty in an investment decision. To reinstate, the standard deviation (σ) value is taken from the Anglo Platinum *Safety* risk assessment.

$$C_{\text{v}} = \sigma\sqrt{t}$$

$$C_{\text{v}} = 0.25 \times \sqrt{5} = 0.56 \tag{4.2}$$

Conveyor Analysis

Table 4.10 outlines the real option investment parameters for the overland conveyor. The stock price (S) is R2644.98, while the exercise price (X) is R5389.1. The time to expiration (t) and the risk-free rate (r_f) remain the same, while the key change in the analysis is the standard deviation (σ) or risk profile of the overland conveyor which is 30%.

Table 4.10: Option-value-metrics for overland conveyor investment

Investment Opportunity	**Call Option**	**Variable**	**Value**
Present Value of cash flows obtained from the investment option	Stock price	S	2644.98
Present value of the expenditure required for project expansion	Exercise (Strike) price	X	5389.1
Period that project expansion option is available for	Time to expiration	t	5 years
The South African prevailing bond rate	Risk free rate of return	r_f	7.53%
Uncertainty in the cash flow generated by the investment option	Volatility of returns	σ	30%

In comparing the risk profiles presented for each investment option some striking patterns emerge. Looking at the CAPEX risk rating of each investment, the road investment has a risk rating of 12 (Table 4.8), which is seen as only *medium* in terms of the risk assessment matrix (Figure 4.8). The conveyor has a CAPEX risk rating of 17 seen in Table 4.11 and is documented as a more *significant* risk in Figure 4.9. By comparing the passive NPV of the two investments, clearly the higher capital expenditure cost of the conveyor has influenced its CAPEX risk profile. In most financial analysis, favourable NPV and low CAPEX risk is regarded as high investment criteria. However, by valuing the risks according to an Anglo Platinum safety rating, the overland conveyor is a more favourable investment option.

By using the *safety* figure displayed in Table 4.11 as our risk profile, our standard deviation or σ value can be established. With a safety risk rating of 14 the overland conveyor is still regarded to have *significant* risk, however, it is less than that of the new road which is 20. By referring to Table 4.3, a 70% safety risk is granted to the overland conveyor. The safety risk is somewhat lower, which has the effect of lowering the financial risk too. To increase the financial value in option pricing terms, the conveyor will have a higher σ value. Thus calculated in the same means by 100% − 70%, we get a 30% financial risk value, resulting in an option pricing σ value of 0.3.

Consequence Type	1-Insignificant	2-Minor	3-Moderate	4-High	5-Major
Likelihood			**Risk Rating**		
5-Almost Certain	11 Medium	16 Significant	20 Significant	23 High	25 High
4-Likely	7 Medium	12 c Medium	17 d Significant	21 High	24 High
3-Possible	4 b Low	8 Medium	13 a Significant	18 Significant	22 High
2-Unlikely	2 Low	5 Low	9 Medium	14 e Significant	19 Significant
1-Rare	1 Low	3 Low	6 Medium	10 Medium	15 Significant

Figure 4.9: 5×5 Conveyor risk assessment matrix (AngloAmerican risk assessment data)

Table 4.11: Risk assessment of an overland conveyor system

Letter	Risk Name	Risk Description	Conveyor Risk Rating
a	EIA	Environmental Effect	13
b	Road Accidents	Road accidents while transporting materials on public roads	4
c	Community Interaction	Effect of project on surrounding community	12
d	CAPEX	Higher than budgeted Capital Expenditure	17
e	Safety	Overall safety rating for surrounding community and employees	14

Having established all the necessary parameters in Table 4.10 to complete the real options analysis, the results of both option mapping metrics are calculated. The first option mapping metric calculated is NPV_{newQ}.

$$NPV_{\text{newQ}} = S/PV_{\text{invest}}$$

Where

$$PV_{\text{invest}} = X \div (1 + r_f)^t$$

Thus

$$NPV_{\text{newQ}} = \frac{2644.98}{5389.1 \div (1.0753)^5} = 0.71 \tag{4.3}$$

The second equation *cumulative volatility* or C_{v} obtains value by attaching some worth to the level of uncertainty in an investment decision.

$$C_{\text{v}} = \sigma\sqrt{t}$$

$$C_{\text{v}} = 0.3 \times \sqrt{5} = 0.67 \tag{4.4}$$

4.3.4 Step 3: $NPV_{\textbf{active}}$

The NPV_{active} section combines both the initial *passive* NPV value found in *Step 1* along with *Step 2's* real option value. The final parameter needed to complete this step is the Black–Scholes option value. Real option value innate in the investment decisions are valued against the passive NPV by taking investment flexibility and risk parameters into account.

New road option value

By substituting Table 4.9 parameters into the Black–Scholes Equation 4.5 below the real option call value for the road option can is attained.

$$\begin{aligned}
\text{BS option Value} =& S\Phi\left[\frac{\ln(S/X)+(r_f+\sigma^2/2)t}{\sigma\sqrt{t}}\right]- \\
& Xe^{-r_f(t)}\Phi\left[\frac{\ln(S/X)+(r_f-\sigma^2/2)t}{\sigma\sqrt{t}}\right] \\
=& 1870\Phi\left[\frac{\ln(1870/3170)+(0.075+0.25^2/2)5}{0.25\sqrt{5}}\right]- \\
& 3170e^{-0.075(5)}\Phi\left[\frac{\ln(1870/3170)+(0.075-0.25^2/2)5}{0.25\sqrt{5}}\right] \\
=& \text{R}308.55\,\text{million}
\end{aligned} \tag{4.5}$$

With the real options value of the investment known, the active NPV can now be calculated.

By using:

$$\begin{aligned}
NPV_{\text{active}} =& NPV_{\text{passive}} + f(\text{real options value}) \\
=& -133.63 + 308.55 \\
=& \text{R}174.92\,\text{million}
\end{aligned}$$

Overland conveyor option value

The same Black–Scholes option valuation analysis is now performed on the overland conveyor. The conveyor variables presented in Table 4.10 are substituted into Equation 4.6 to find the real option call value.

$$\begin{aligned}
\text{BS option value} =& S\Phi\left[\frac{\ln(S/X)+(r_f+\sigma^2/2)t}{\sigma\sqrt{t}}\right]- \\
& Xe^{-r_f(t)}\Phi\left[\frac{\ln(S/X)+(r_f-\sigma^2/2)t}{\sigma\sqrt{t}}\right] \\
=& 2664.98\Phi\left[\frac{\ln(2644.98/5389.1)+(0.075+0.3^2/2)5}{0.3\sqrt{5}}\right]- \\
& 5389.1e^{-0.075(5)}\Phi\left[\frac{\ln(2644.98/5389.1)+(0.075-0.3^2/2)5}{0.3\sqrt{5}}\right] \\
=& \text{R}412.22 \text{ million}
\end{aligned} \tag{4.6}$$

With the real options value of the investment known, the active NPV can now be calculated.

By using:

$$\begin{aligned}
NPV_{\text{active}} =& NPV_{\text{passive}} + f(\text{real options value}) \\
=& -376.9 + 412.22 \\
=& \text{R}35.32\,\text{million}
\end{aligned} \tag{4.7}$$

In observing the NPV_{active} values of both the *new road* and the *conveyor* a more favourable investment criteria is found. While passive NPV is unfavourable, real option valuation finds value in the risk and deferral of an investment. To further supplement the real options value, the active mapping framework is illustrated in the next section, giving added insight to the investment decision.

4.3.5 Interim Data Overview

Before moving onto the active mapping framework it is expedient to view key aspects in the Anglo Platinum case study data analysis. Table 4.12 below provides a summary of the values calculated in each step of the data analysis. Moreover observations and explanations provide supplementary insight into the summarised data.

Looking at the data overview analysis in Table 4.12 there are key observations that can be explored. In Step 1 of the table, there is little denying the

Table 4.12: Data overview of analysis section

Data Analysis	Variable	New Road	Conveyor
Step 1	$NPV_{\mathbf{passive}}$	(133.63)	(376.9)
Step 2	S	1870.45	2664.98
	X	3170	5389.1
	r_f	7.53%	7.53%
	t	5 years	5 years
	σ	0.25	0.3
	$NPV_{\mathbf{newQ}}$	0.85	0.71
	$C_{\mathbf{v}}$	0.56	0.67
Step 3	**Black–Scholes Option Value**	308.55	412.22
	$NPV_{\mathbf{active}}$	174.92	35.32

unattractiveness of the investment options. In both cases the passive NPV values are negative and little potential shines from the cash flow statements. The conveyor option has a lower NPV, clearly due to the higher capital investment cost in exercising the investment. However, according to the predicted revenues, the overland conveyor has a greater potential of higher future cash flows from the investment option. This statement is reinforced by the conveyor S figure of R2664.98 million compared to the new road figure of R1870.45 million.

Moving down to the Black–Scholes option value in Step 3, it is surprising to see that the conveyor is now favoured. This is directly due to the higher future cash flows from the investment (S) as well as the higher standard deviation or σ value. Option value increases with the σ value and this is as a result of the conveyor being a lower safety risk compared to the new road. In the case of option value, we will give a safer investment, a higher reward as it is beneficial in financial terms to that investment. Of course there are cases where a high standard deviation can overvalue the investments, but this is where the Step 2 equations present themselves.

Step 2 variables as they are presented in Table 4.12 do not indicate a great deal. Obviously the differences can be seen such as the road, which has a higher value-cost (NPV_{newQ}) ratio of 0.85 compared to the conveyors of only 0.71. However, the true potential is illustrated in the use of the active mapping tool. These two parameters, namely, NPV_{newQ} and C_{v} use the exact same metrics used in the Black–Scholes valuation, yet they are plotted independently within the option mapping framework to actively plot the investment decision.

4.4 Active Mapping Framework

While the active NPV (NPV_{active}) looks at the contrast in both the conventional NPV value and the real options value, the *active map* can add perspective. Perspective comes in the form of various decisional criteria, six in total, which provide guidance to an otherwise irrelevant real option value. Additionally the active mapping framework hopes to influence a more engaged and functional participation in investment decisions. Variables can be tweaked, modified or experimented upon to understand the potential risks, returns and factors influencing the investment.

4.4.1 Mapping of Investment Decision

Using the value adding real option values from NPV_{newQ} and C_{v} the *new road* and *conveyor* options can be plotted within a six decisional criteria option map according to two primary axis. Instead of viewing an investment on a purely "invest" or "don't invest" NPV basis, multiple decisional criteria can be used. Ultimately creating a more active investment decision making process by illustrating both present and future investment potential. The active map of the road and conveyor investments are illustrated in Figure 4.10 and Figure 4.11 in their respective sections below.

By using the active map unfavourable investment decisions are still valued according to a flexible mapping framework. NPV metrics such as value-to-cost are not the final decisional criteria as cumulative volatility also influences the call option value. The vertical line aligned with one on NPV_{newQ} or the value-to-cost axis represents the usual NPV criteria. Should the value-to-cost be greater than one, this represents the common, positive NPV. Less than one, then clearly represents the negative NPV. The second axis, separated by the horizontal line, represents the amount of risk attributed to the investment. In other words, this line can be moved up or down depending on how a company evaluates various risk profiles for various asset classes. In the case study 0.4 was the preferred risk assessment value.

Active mapping of the road investment

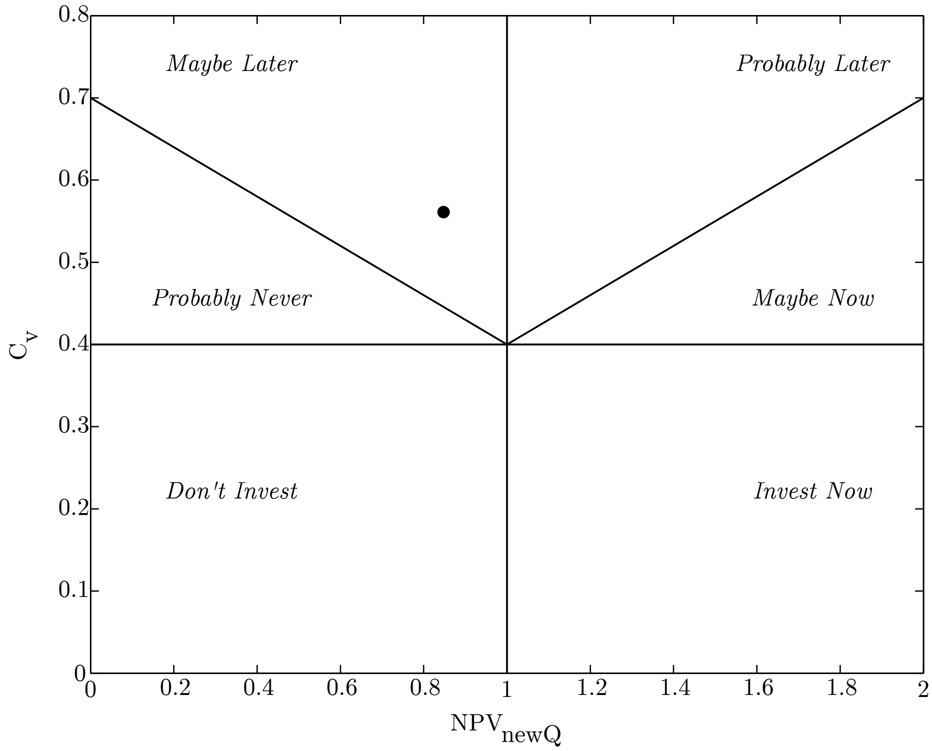

Figure 4.10: Active mapping space reflecting the investment of building a new road

The active mapping diagram shown in Figure 4.10 illustrates that currently the *new road* investment has a low NPV_{newQ} or weak value-to-cost ratio. The investment, however, is not far from becoming more favourable. In conventional DCF analysis, a low NPV simply means "don't invest", in this case the option map suggests "maybe later". Why then maybe later? By considering the second metric of cumulative volatility (C_{v}) and the risk structure of the option space, this asset holds some risk and uncertainty. Usually risk carries with it negative connotations, but option theory suggests otherwise. Option theory considers the possible value inherent in risk, as in many investment cases, with high risk, comes high reward. Obviously high risk should not be considered high value, but the option space allows one to recognise how much risk is acceptable.

Instead of just considering the investment a "don't go", the active mapping space recognises that with an acceptable amount of risk the investment could prove more fruitful. By actively engaging in the mapping space with a strategic scenario analysis, the investment can be tracked or altered based on the results. Due to the nature of the map, by actively adding updated information, the investment will move within the mapping space. For example using Figure 4.10, should revenue streams increase with time, the value-to-cost ratio will become more favourable, possibly higher than one. Consider along with better revenue streams the lowered risk profile of the investment. In this case, the investment option could easily move from a "maybe later" quadrant to a "maybe now" section. From a traditional DCF and NPV analysis, it would be difficult to review the potential of an investment from a "go" or "don't go" decisional criteria. With an active mapping space, the interactive, illustrative, decision making tool provides the strategic insight to say, "maybe later".

Active mapping of the conveyor investment

The active map of the conveyor is illustrated by Figure 4.11. The result of the investment is plotted according to the results in Step 2, namely the NPV_{newQ} and C_{v} variables.

The active map provided plots the resultant findings of Step 2. Naturally, the active mapping tool does not give us more than what we currently know on the investment. By comparing it to the road investment in Figure 4.10 small differences can be distinguished. Firstly the conveyor has a lower value-to-cost ratio due to the higher capital expenditure required. The risk profile of the conveyor however is higher than that of the road. As expressed upon, the risk value for the conveyor is higher than the road due to the better safety rating. The overall Black–Scholes option value is higher for the conveyor, due party

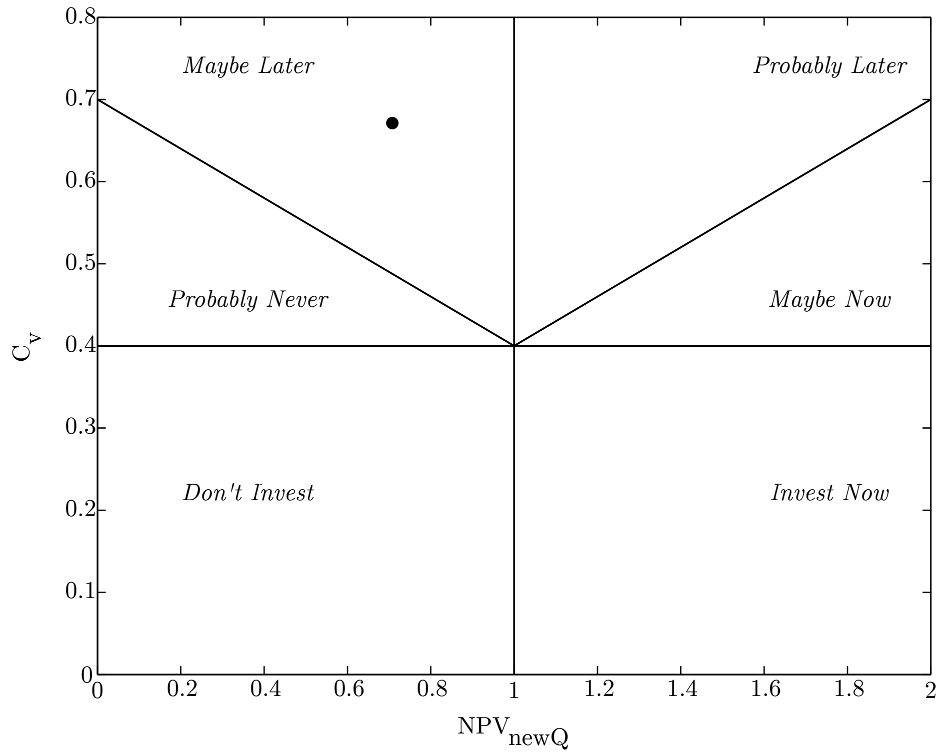

Figure 4.11: Active mapping space reflecting the investment of building a conveyor

to the higher value added risk metric.

The scenario analysis to follow provides strategic insight into the option-to-defer. The case study presents the option to defer either investment for five years. Within this time, a number of conditional parameters are likely to change. Using scenario analysis, investment strategies can be tracked and plotted based on variable modifications.

4.4.2 Scenario Analysis

Scenario analysis illustrates the active use of a visual option mapping space for the real options presented in the case study. The scenarios created from the case study present realistic market conditions based on industry standards. Other than the base case presented there are three additional scenarios. The scenarios implemented are namely: *Pessimistic*, *Optimistic* and *Progressive* scenarios. Each investment is exposed to the various scenarios presented and mapped within the case specific mapping space. Each investments active map is then discussed in greater detail providing clarity and perspective.

Table 4.13 given below represents the parameter definitions for the option mapping scenario analysis to be carried out. The *Base Case* is the standard initial investment presented in the case study. From the base case there are then three other scenarios tested. They are the *Pessimistic*, *Optimistic* and *Progressive* scenarios. Each scenario is now discussed, giving light to the parameter changes chosen.

Table 4.13: Scenario analysis for an active mapping space

Variables	Base Case	Pessimistic	Optimistic	Progressive
S	s	s	$s \times 1.5$	$s \times 1.5$
X	x	x	x	x
r_f	r_f	r_f	r_f	r_f
T	t	t	t	$t - 2$
σ	σ	$\sigma - 5\%$	σ	$\sigma - 5\%$

Pessimistic This case illustrates the negative nature of a lower variance (σ) value. Real options finds value in the variance through the cumulative distribution varaible.

Optimistic The optimistic case assumes all variables remain constant, except for the *present value of assets as a result of the investment* (S). This increases the value-to-cost ratio.

Progressive The progressive scenario is one of the more complex scenarios. It follows the same *optimistic* S increase, but also has a reduced risk (σ) and time (t) change. The assumption is that the investment is in an optimistic value-to-cost range, and with increased confidence in the investment, the risk profile has been lowered. In addition, instead of now deferring the investment for the initial period, two years are now shed off the deferral time t.

Scenario analysis: Road Investment

This section presents the active map results of the new road based on scenarios in Table 4.14. The results are plotted on Figure 4.12 below and accompanied with a brief synopsis.

Table 4.14: Option mapping scenario parameters: New road

Variable	Base Case	Pessimistic	Optimistic	Progressive
S	1870.45	1870.45	2805.68	2805.68
X	3170	3170	3170	3170
r_f	0.075	0.075	0.075	0.075
T	5	5	5	3
σ	0.25	0.2	0.25	0.2
Real option value				
$NPV_{\mathbf{newQ}}$	0.85	0.85	1.27	1.1
$C_{\mathbf{v}}$	0.56	0.45	0.56	0.35
Black–Scholes Option Value	308.55	224.34	915.56	520.03
$NPV_{\mathbf{active}}$	174.92	90.71	781.93	386.4

The first case discussed is the initial *base case*, with a low value-to-cost ratio and reasonable risk profile, the base case fits into a "maybe later" section. The base case presents a high enough Black–Scholes option value of R308.55 million to lift the active NPV (NPV_{active}) to R174.92 million. The value attached to the risk profile (C_{v}) of the base case is more evident as the analysis moves on to the pessimistic case. The pessimistic scenario demonstrates the value assigned to a certain risk or cumulative volatility profile. By changing the risk assigned to the investment from 25% to only 20%, the investment has become less favourable moving from "maybe later" to a "probably never" section. The active map recognises the lack of potential in less certain investments and the pessimistic scenario clearly highlights the result of low value-to-cost as well as low cumulative volatility metrics. The influence of the

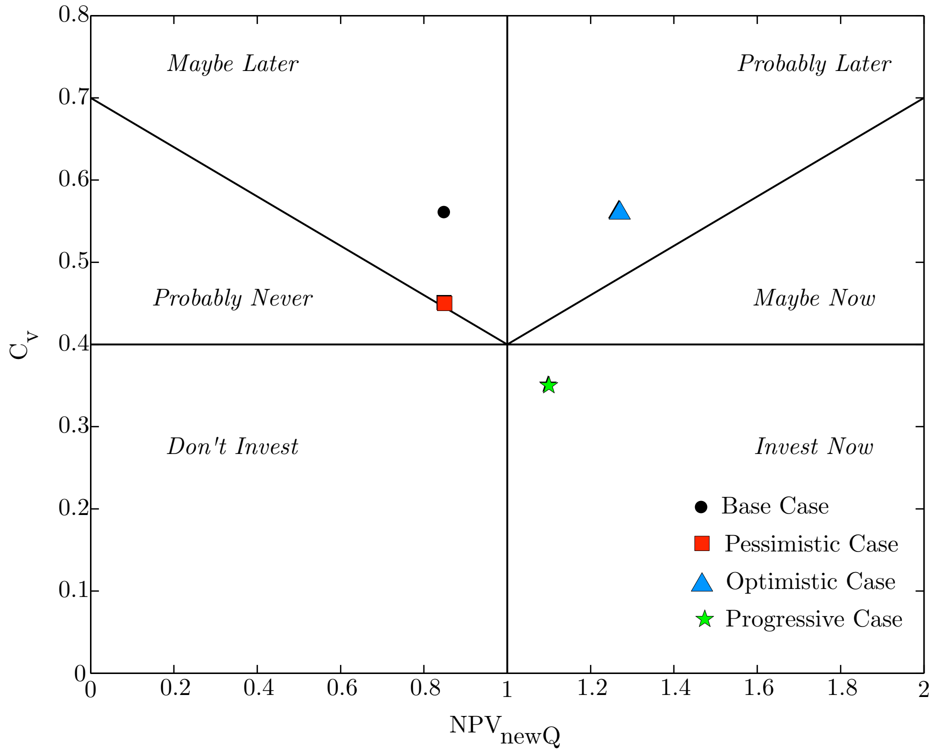

Figure 4.12: Active mapping scenario analysis: New Road

lowered σ value transcends to the Black–Scholes call option value which has decreased to R224.34 million.

The Optimistic scenario explores the possibility of higher revenues generated. The optimistic case emulates a "best" case scenario of Anglo Platinum's sensitivity analysis. The increase is based on three principle changes which are metal prices, CPI rates and the Rand/Dollar exchange. The forecast for these changes are reviewed every quarter. With the flexibility of the active mapping framework, updates are easily implemented with dynamic, real time mapping results. The result of the optimistic scenario is a favourable value-to-cost ratio with the same risk profile as the base case. The NPV_{newQ}, value adding metric has increased to 1.27 and the Black–Scholes option value is at it's highest at R915.56 million. The active NPV has escalated to R781.93 million due to the high option value. The active NPV (NPV_{active}) figure is sceptical as the option value is uncharacteristically high. By plotting these parameters on the active map a "probably later" decisional criteria is reflected. Looking at all the variables this is better judgement to follow as although the return is favourable, the investment should still be watched for some time, especially with the high option value and associated risk.

The final scenario, the Progressive case, actively follows on from the optimistic scenario. It values the investment with a two year decrease in deferral time from five years to three years. In addition, with increased confidence in operations the risk is reduced to 20%. The reduction in deferral time has lowered the NPV_{newQ} value from 1.27 to 1.1 as less interest earning value is generated. The scenario results in a convincing value-to-cost ratio as well as low risk profile placing the investment in an "Invest Now" space. The smaller time period and lowered risk profile ($C_{\text{v}} = 0.35$) have reduced the Black–Scholes option value to R520.03 million. Notice how the Black-Scholes option value is lower than the optimistic case, but the decisional criteria based on the active map favours the progressive scenario.

To demonstrate how the active map breaks down the Black–Scholes option value is seen in the difference between Black–Scholes option values of the Optimistic and Progressive scenarios. While the optimistic case has a large option value of R915.56 million compared to the progressive value of R520.03 million, the map still prefers the latter. Although the option value of the optimistic scenario is higher, the active map recognizes the dangers of a higher risk profile as well as a longer time period. This is important as a high option value does not always indicate that the investment is sound. By mapping the investment the amount of risk associated with a given rate of return can actively be seen allowing more sound strategic decisions to be formulated.

Scenario analysis: Conveyor Investment

The active mapping scenario analysis of the conveyor investment is displayed in the following section. While Table 4.15 summarises the relevant parameters, Figure 4.13 displays the accompanying results within the active mapping space.

Although a similar trend can be seen in the results, the active map presents far less favourable results for the conveyor system. For the most part the high capital expenditure limits the value-to-cost potential, especially in the time

Table 4.15: Active mapping scenario parameters: Conveyor

Variable	**Base Case**	**Pessimistic**	**Optimistic**	**Progressive**
S	2664.98	2664.98	3997.47	3997.47
X	5389.1	5389.1	5389.1	5389.1
r_f	0.075	0.075	0.075	0.075
T	5	5	5	3
σ	0.3	0.25	0.3	0.25
	Real	**Option**	**Values**	
$NPV_{\mathbf{newQ}}$	0.71	0.71	1.06	0.92
$C_{\mathbf{v}}$	0.67	0.56	0.67	0.43
Black–Scholes Option Value	412.22	295.42	1164.40	568.62
$NPV_{\mathbf{active}}$	35.32	(81.48)	787.5	191.72

period used in the analysis. The base case indicates the conveyors low return on investment as well as high uncertainty and risk profile, with a cumulative volatility (C_{v}) value of 0.67, well above the 0.4 boundary. The Black–Scholes option value for the base case is R412.22 million, resulting in an active NPV of just R35.32 million and classifying the investment as a "maybe later" option.

The Pessimistic case with a lowered risk variable remains in the "maybe later" section. However this is primarily due to a comparatively high risk profile. The return on investment is low, as is the Black–Scholes call option value of R295.42 million. The active NPV is negative and the active map has only considered the investment due to a high cumulative volatility profile.

The Optimistic scenario considers an increase in the revenue stream and is the only scenario which offers a favourable (only slight) value-to-cost profile. The standard deviation is unchanged from the base case, rendering a high cumulative volatility and placing the investment in a "maybe later" section. The high risk profile along with increased revenues has spiked the Black–Scholes option value to R1164.40 million and the NPV_{active} to R787.5 million. The high option value is misleading, however, the active map rightly indicates that the investment should be deferred to a later stage due to high risk an only barely favourable NPV_{newQ}.

The Progressive scenario gives an honest perspective of the conveyor investment. The factor influencing this scenario considerably is the reduced deferral time of three years. High capital expenditure has already weakened investment prospects and a smaller deferral period provides little real option growth. The conveyor option has high potential with higher forecast revenue streams, however to make a more accurate or informed decision, more time is needed. The progressive scenario has moved from the "probably later" section to a low corner of the "maybe later" section. The low value-to-cost (NPV_{newQ}) metric is as a result of a poor replicating portfolio investment value. The smaller time period means less interest value is earned on the government bonds bought to sufficiently hedge the deferred investment over inflation. The progressive scenario does have a high Black–Scholes option value of R568.62 million but the active map sees no consolation in this.

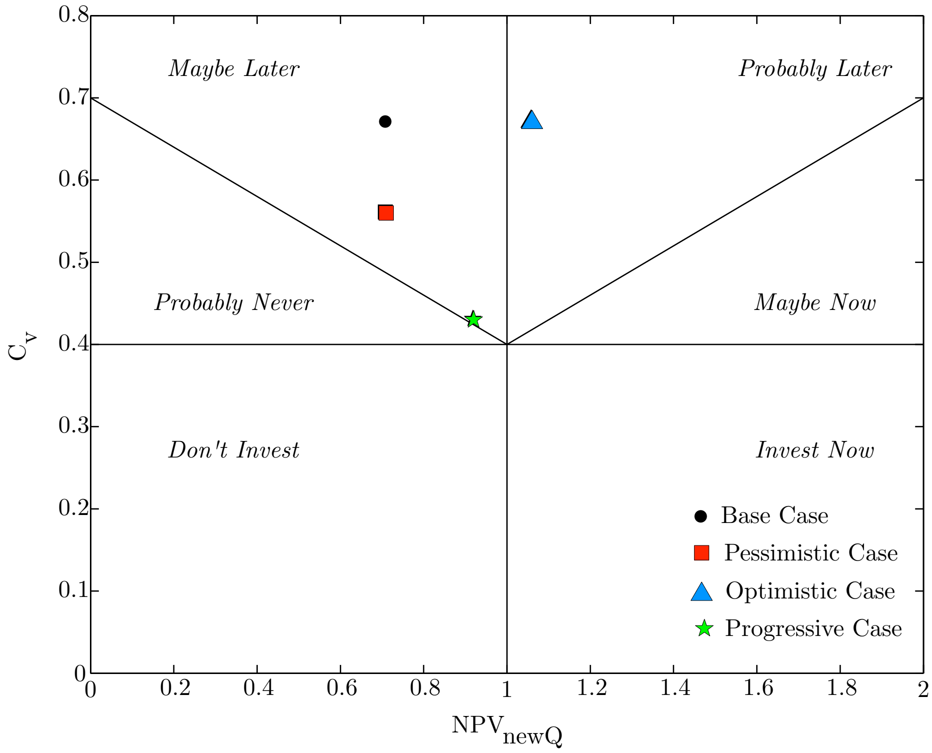

Figure 4.13: Active mapping scenario analysis: Conveyor

4.5 Results and Comments

This section provides final interpretations of the scenario analysis results of both the new road and conveyor investments. Both initial NPV's where highly unfavourable, the conveyor more so due to the higher capital expenditure. In the passive NPV analysis, the respective investments were broken down into a Phase 2 NPV analysis. By isolating the primary investments in question the direct cash flow related to either the new road or conveyor could be calculated. Step 1 significantly improved the NPV as high preliminary expenditures were eliminated, allowing future revenues to compensate for high capital expenditure and working costs. Step 1 ultimately provided better yearly present value results offering a improved understanding of the investments influence on the gain in revenue streams.

Steps 2 and 3 introduced the primary real option parameter used in calculating the option mapping metrics NPV_{newQ} and C_{v}. In addition the Black–Scholes option values were calculated, enabling the final active NPV value to be determined. Table 4.16 presented below gives a summary of key values calculated in each step of the analysis. As seen in the results, by simply valuing only the investment in Step 1, and excluding costs unrelated to the primary investments, the NPV's improved dramatically. The new road investment improved from −R4483.7 million to −R133.63 million while the conveyor improved from −R5473 million to −R376.9 million. By simply eliminating preliminary start-up costs unrelated to the primary investments, the passive NPV decisional criteria improves significantly.

Table 4.16: Final results overview of analysis section (Rand Million)

Data Analysis	Variable	New Road	Conveyor
DCF	**NPV**	(4483.7)	(5473)
Step 1	$NPV_{\mathbf{passive}}$	(133.63)	(376.9)
Step 2	$NPV_{\mathbf{newQ}}$	0.85	0.71
	$C_{\mathbf{v}}$	0.56	0.67
Step 3	**Black–Scholes Option Value**	308.55	412.22
	$NPV_{\mathbf{active}}$	174.92	35.32

Based on the assumptions and calculations presented in conjunction with Anglo Platinum's risk assessments the cumulative volatility (C_{v}) metric was determined. The value-to-cost or NPV_{newQ} metric was determined using a replicating portfolio by investing in government bonds. Using the parameters determined in the Step 2 process, the Black–Scholes option value could be calculated. The Black–Scholes value calculated is for a single-stage European deferment call option. The positive values illustrated in Table 4.16 point out the inherent value present in each investment option. The higher conveyor value of R412 million is due to a higher standard deviation (σ) as well as present value of assets (S).

The final result is the active NPV calculation which is the sum of the passive NPV and the Black–Scholes option value. In the Anglo Platinum case study, the road had an NPV_{active} of R174.92 million while the conveyors NPV_{active} was R35.32 million. The active NPV has combined both conventional DCF analysis along with real options valuation techniques. The final passive NPV being the backbone, with three of the five option value parameters originating from the original Anglo Platinum DCF forecast. To further illustrate the flexibility of real options, the active mapping framework combined with a scenario analysis was staged.

By using an active mapping framework, the value attained through the Black–Scholes equation could be broken down into two value adding metrics C_{v} and NPV_{newQ}. The investment scenario is then plotted within the mapping space landing within one of six active decisional criteria sections. It provides insight into an otherwise insipid Black–Scholes option value. By actively mapping the investment, strategic insight and active managerial participation inspire better decision making. Table 4.17 presents the final results of the various scenarios. While some detail of the actual active maps are provided within the *data analysis* section, this serves to give detailed analysis on the governing variables and results.

The scenario analysis was executed using three principle cases, namely *Pessimistic*, *Optimistic* and *Progressive*. The variations implemented were in accordance with standard industry assumptions. In addition to being plotted according to value adding metrics, the option value was calculated along with the final active NPV. Although most results have been discussed throughout the case study analysis, this serves to illustrate final thoughts regarding individual assessments as well as the overall decisional stance.

Beginning with the new road, the active map represented by Figure 4.12 gave a spread of results across numerous decisional sections. This was interesting as it illustrated completely different decisional criteria compared to most NPV and option value cases. Here it would simply be illustrated by a single numerical figure with no other insight, limiting the decision makers overall perception. The second active map, that of the conveyor is represented by Figure 4.13. In this scenario analysis, the results are far more clustered,

Table 4.17: Final active mapping scenario parameters: (Rand Millions)

Variable	Base Case	Pessimistic	Optimistic	Progressive
New Road				
$NPV_{\mathbf{newQ}}$	0.85	0.85	1.27	1.1
$C_{\mathbf{v}}$	0.56	0.45	0.56	0.35
Black–Scholes Option Value	308.55	224.34	915.56	520.03
$NPV_{\mathbf{active}}$	174.92	90.71	781.93	389.4
Conveyor				
$NPV_{\mathbf{newQ}}$	0.71	0.71	1.06	0.92
$C_{\mathbf{v}}$	0.67	0.56	0.67	0.43
Black–Scholes Option Value	412.22	295.42	1164.40	568.62
$NPV_{\mathbf{active}}$	35.32	(81.48)	787.5	191.72

mostly around the “maybe later” decisional section. Although seemingly uninformative it gives a realistic perception of the conveyor investment which even in conventional NPV terms is difficult to estimate. Furthermore, the unrewarded conveyor investment looks unattractive from a capital expenditure view point, but option values see high value. High value is acknowledged in favourable risk criteria and higher present values of cash flows from exercising the investment (S).

The Pessimistic case presented a lowering of only the risk profile associated with the investment. Although using only a small adjustment of 5% the result was received differently in either case. The aim of the pessimistic case was to identify the option value associated with risk, and its affect on the investment. In both cases the investments option value dropped, the road value fell to R224.34 million while the conveyor to R295.42 million. There was a significant drop in both cases, however the significance of this drop relative to the base case must be considered. This was represented in the active mapping framework. While the conveyor remained in the “maybe later” (Figure 4.13) section, the road option plummeted to a more negative “probably never” (Figure 4.12) section. The higher risk attribute attached to the conveyor allows for more risk, however the road does not and thus significant value is lost. This is directly related in many ways to the safety assessment origin of the risk evaluation. As with a higher safety risk, the investment would also be deemed less favourable.

In the Optimistic scenario, the revenues of each investment were increased with the same multiple. Nothing else is changed and the aim is to assess the difference in the value-to-cost NPV_{newQ} metric which is more favourable. The optimistic result showed very high gains in the Black–Scholes option values, in both cases results almost tripled from the base case. From a numerical point of view this is great news, but the active maps illustrate a more honest viewpoint. In the road investment map in Figure 4.12 the investment moves comfortably into the "probably later" section with acceptable risk and good returns on investment. The conveyor however, even with a higher option value, is only just favourable on the the option map Figure 4.13. In fact the investment plot is only just within the "probably later" section with a high cumulative volatility of 0.67. This section highlights the misrepresentation of the option value, in addition the misrepresentation of an active NPV figure. Further leading to the positive supplementary benefits of an active mapping tool. Basing the optimistic decision to invest on the NPV_{active} values, the choice would have been the conveyor. As the option map points out though, the road investment is the safer choice with higher returns relative to the investment cost.

The final progressive scenario adapts three parameters. It follows a basic premise that the optimistic case has been pushed forward due to increased confidence in the investment. This means that the risk has reduced (-5%) and so too has the deferral time (3 years) of the investment decision. This stretches the equation somewhat on the positive side as revenues have increased. On the other hand option value decreases due to the risk decrease. Likewise then, the reduction in time will mean less interest earning value is earned through replicating government bond investments adding to a loss in option value. As a result the Black–Scholes values drop from the optimistic range as expected, however the conveyor drops more in final NPV_{active} value to R191.72 million compared to the roads R389.4 million. Attention must be drawn to the active maps of this progressive scenario. In the road case presented by Figure 4.12, the lowered risk profile has placed the investment in the "invest now" section. It has lost on the value-to-cost metric, however the investment is deemed acceptable to invest in. The conveyor on the other hand has moved into the "maybe later" section and bordering on "probably never" this is due to the loss in all round value attributes. Also noteworthy to mention is the road options optimistic versus progressive scenarios. While the optimistic scenario boasts a higher option value and active NPV, the active map still favours the progressive scenario. This is the unique power of the active map which gauges the metrics responsible for the option values calculated. Thus giving more insight into the capital budgeting of and investment than single NPV figures presented against one another, with little insight or perception.

In closing the Case Study in Chapter 4, the investment choice that is chosen in this study is the new road. Using the information in the Case Study and the results based on the combined DCF and ROA framework the preferred option remains the road. Although the conveyor investment echoes with future potential and a lower risk profile, it is still highly volatile given the prescribed capital budgeting period. The new road investment proved more dynamic and flexible in the scenario analysis with a more positive active mapping path structure. The Base Case illustrated modest future potential while the Optimistic and Progressive cases were both highly favourable, easily overcoming the value-to-cost boundaries as well as holding an adequate cumulative volatility. While the conveyor remains an interesting investment prospect, high capital expenditure and rife uncertainty cloud the future prospects of this investment.

Chapter 5

Closure

5.1 Overview

In all PAM concentrated organisations one of the most important decisions faced is the capital budgeting of either acquiring or creating a new physical asset. The majority of organisations implement inflexible, stagnant DCF techniques which do not account for the strategic value characteristic of real options. Chapter 1 of the study introduces the broad based outline of the thesis along with the problem statement and hypothesis.

Chapter 2 consists of the three primary research topics integrated in this thesis. They are Physical Asset Management (PAM), Discounted Cash Flow (DCF) and Real Options Analysis (ROA). The topical field of PAM forms the broad based framework where the subject of capital budgeting is both highly important and relevant as pointed out within the Public Available Specification 55 (PAS 55). The study investigates the capital budgeting of physical assets within a PAM delineation. Chapter 2 highlights the widespread use of DCF capital budgeting techniques along with deficiencies and shortcomings. Amongst these deficiencies the two most emphasised inadequacies are in the areas of risk and flexibility. Conversely, the financial option based technique of ROA revels in the valuation of physical assets by accounting for value in risk, uncertainty and managerial flexibility. By exploiting the differences and similarities between DCF and ROA, a combined capital budgeting framework was created. Moreover a visually active option mapping framework is used to complement the combined framework and supplement capital budgeting decisions.

Based on the formulation of a combined capital budgeting technique, Chapter 3 sketches a real options active mapping framework, based on the foundations of DCF analysis. By applying real options techniques, replicating portfolios and a measure of industry specific volatility, ROA accounts for the value in risk and flexibility. In efforts to combat the one number syndrome of conventional DCF decisional criteria, the active mapping tool is integrated into the combined capital budgeting technique. The active mapping tool provides two metrics with six decisional criteria compared to DCF's NPV which consists of one metric and two decisional criteria. Furthermore, the combined active mapping framework incorporates a functional and dynamic scenario analysis whereby varying future prospects can be better understood as well as actively managed.

In validating both the use and applicability of the combined active mapping framework, a Case Study is carried out in Chapter 4. The case study is done in conjunction with Anglo Platinum and investigates the capital budgeting investment of a new road and an overland conveyor. Using the framework outlined in Chapter 3 and a host of scenarios, the mutually exclusive investments are gauged using the active mapping framework.

5.2 Limitations

In implementing a combined ROA and DCF active mapping tool within a PAM framework, some key limitations are highlighted. Although some limiting assumptions and constraints have already been outlined within the study, they will not be repeated here. The limitations associated with the study are outlined below.

i) *Uncertainty and risk:* Uncertainty and risk are a primary driver in the option value of an investment. Due to a lack of data aligning safety risk with financial risk, value adding assumptions had to be made.

ii) *Real options overvalue investments:* In this study, strategic options are aligned with the new road and conveyor investments to assign inherent option value which is disregarded in conventional DCF analysis. The real options are calculated due to the strategic options and flexibility innate in the investments. High project risk and uncertainty can drive option value higher. Due to the assumptions presented and the lack of comparative data available, it is difficult to evaluate the option values calculated. However, by implementing a scenario analysis, along with the visual active mapping framework, high option value is balanced out with the plotting of investment scenarios.

5.3 Recommendations for Future Research

Based on limitations found in the thesis along with renewed insight into the field of ROA and DCF capital budgeting techniques there are two primary areas where further research can be beneficial.

i) *Risk and uncertainty:* In the unpredictability of real business investment conditions there can be many risks unaccounted for. More research into quantifying risks and combining varying risk classes by some measure can be highly advantageous.

ii) *Real options analysis techniques:* Incorporating more real options techniques can be beneficial in gauging the option values on multiple platforms. This can provide a range of option values which can discredit the negative connotations associated with real option over valuation.

5.4 Conclusion

The objective of this thesis was to implement a combined ROA and DCF active mapping framework in overcoming the shortcomings of traditional DCF techniques within a PAM framework. The combined active mapping tool was validated in its application to a physical asset Case Study provided by Anglo Platinum. By applying the active mapping tool and proposed Chapter 3 framework, the objectives listed in Chapter 1 were successfully fulfilled. In conclusion, the null hypothesis of this study is rejected. Therefore, a combined ROA and DCF active mapping tool can be used to supplement the capital budgeting of investments within a PAM framework.

List of References

Amadi-Echendu, J., Willett, R., Brown, K., Hope, T., Lee, J., Mathew, J., Vyas, N. and Yang, B. (2011). What is engineering asset management? *Definitions, Concepts and Scope of Engineering Asset Management*, pp. 3–16.

Amram, M. and Kulatilaka, N. (1999). *Real options: Managing strategic investment in an uncertain world*. Harvard Business School Press.

Amram, M. and Kulatilaka, N. (2000). Strategy and shareholder value creation: The real options frontier. *Journal of Applied Corporate Finance*, vol. 13, no. 2, pp. 15–28.

Arnold, T. and Shockley Jr, R. (2002). Real options, corporate finance, and the foundations of value maximization. *Journal of Applied Corporate Finance*, vol. 15, no. 2, pp. 82–88.

Aswath, D. (1999). The promise and peril of real options. *New York University*.

Athwal, B., Harmantzis, F. and Tanguturi, V. (2005). Replacing centric voice services with hosted voip services–a real options approach. In: *Proceedings of the 16th International Telecommunications Society (ITS) European Regional Conference*.

Baker, H. (2011). Capital budgeting valuation: financial analysis for today's investment projects (hardback)(series: robert w kolb series). *Recherche*, vol. 67, p. 02.

Baker, H., Dutta, S., Saadi, S., Hall, G. and Street, U. (2011). Management views on real options in capital budgeting. *Journal of Applied Finance*, vol. 21, no. 1, pp. 18–29.

Balasubramanian, P., Kulatilaka, N. and Storck, J. (2000). Managing information technology investments using a real-options approach. *The Journal of Strategic Information Systems*, vol. 9, no. 1, pp. 39–62.

Benninga, S. and Tolkowsky, E. (2002). Real optionss an introduction and an application to r&d valuation. *The Engineering Economist*, vol. 47, no. 2, pp. 151–168.

Bierman, H. (1988). *Implementing capital budgeting techniques*. Ballinger Pub. Co.

Bierman, H. and Smidt, S. (2006). The capital budgeting decision economic analysis of investment projects (pod).

Black, F. and Scholes, M. (1973). The pricing of options and corporate liabilities. *The journal of political economy*, pp. 637–654.

Block, S. (2007). Are real options actually used in the real world? *The Engineering Economist*, vol. 52, no. 3, pp. 255–267.

Bonds, R.R.S. (2012). Current interst rates.
Available at: `https://secure.rsaretailbonds.gov.za/Rates.aspx`

Borison, A. (2005). Real options analysis: where are the emperor's clothes? *Journal of Applied Corporate Finance*, vol. 17, no. 2, pp. 17–31.

Bowman, E. and Moskowitz, G. (2001). Real options analysis and strategic decision making. *Organization Science*, pp. 772–777.

Boyle, P. (1986). Option valuation using a three-jump process. *International Options Journal*, vol. 3, no. 7-12, p. 1.

Boyle, P. (1988). A lattice framework for option pricing with two state variables. *Journal of Financial and Quantitative Analysis*, vol. 23, no. 1, pp. 1–12.

Brealey, R. (1991). *Principles of corporate finance*. Tata McGraw-Hill Education.

Brounen, D., De Jong, A. and Koedijk, K. (2004). Corporate finance in europe: Confronting theory with practice. *Financial management*, pp. 71–101.

Bruner, R., Eades, K., Harris, R. and Higgins, R. (1998). Best practices in estimating the cost of capital: survey and synthesis. *Financial Practice and Education*, vol. 8, pp. 13–28.

Butler, J. and Schachter, B. (1989). The investment decision: Estimation risk and risk adjusted discount rates. *Financial Management*, pp. 13–22.

Carr, P. (1988). The valuation of sequential exchange opportunities. *The Journal of Finance*, vol. 43, no. 5, pp. 1235–1256.

Chance, D. and Peterson, P. (2002). Real options and investment valuation.

Childs, P., Ott, S. and Triantis, A. (1998). Capital budgeting for interrelated projects: A real options approach. *Journal of Financial and Quantitative Analysis*, vol. 33, no. 3.

Chopey, N. and Fisher-Rosemount, J. (1999). Put a smart face on asset management; intelligent field devices can make plant maintenance more effective, less costly. *Chemical Engineering*, vol. 106, no. 2, p. 108.

Clark, J., Hindelang, T. and Pritchard, R. (1984). *Capital budgeting*. Prentice-Hall Englewood Cliffs (NJ).

Copeland, T. and Antikarov, V. (2002). Real options: A practitioner's guide. 2001. *Texere LLC*.

Correia, C. Flynn, D.U.E. and Wormald, M. (2011). *Financial Management 7th Edition*. Juta and company ltd.

Cox, J., Ross, S. and Rubinstein, M. (1979). Option pricing: A simplified approach. *Journal of financial Economics*, vol. 7, no. 3, pp. 229–263.

Creswell, J. (2009). *Research design: Qualitative, quantitative, and mixed methods approaches*. Sage Publications, Inc.

Creswell, J. and Clark, V. (2007). *Designing and conducting mixed methods research*. Sage Publications, Inc.

Dai, Q. *et al.* (2000). Analyzing investments in object-oriented middleware: An options perspective.

Damodaran, A. (2001). *The dark side of valuation*. FT Press.

Damodaran, A. (2002). *Investment valuation: Tools and techniques for determining the value of any asset*. John Wiley & Sons Inc.

Del Sol, P. and Ghemawat, P. (1999). Strategic valuation of investment under competition. *Interfaces*, vol. 29, no. 6, p. 42.

Dixit, A. and Pindyck, R. (1994). *Investment under uncertainty*. Princeton Univ Pr.

Dixit, A. and Pindyck, R. (1995). The options approach to capital investment.

Ekstrom, M. and Bjornsson, H. (2003). Evaluating it investments in construction. Tech. Rep., CIFE Technical Report.

Fernandez, P. (2009). The equity premium in 150 textbooks.

Filbeck, G. and Lee, S. (2000). Financial management techniques in family businesses. *Family Business Review*, vol. 13, no. 3, pp. 201–216.

Fischer, S. (1978). Call option pricing when the exercise price is uncertain, and the valuation of index bonds. *The Journal of Finance*, vol. 33, no. 1, pp. 169–176.

Ford, D., Lander, D. and Voyer, J. (2004). Business strategy and real options in the context of large engineering projects. *J. Competitiveness*.

Geske, R. (1979). The valuation of compound options. *Journal of financial economics*, vol. 7, no. 1, pp. 63–81.

Gitman, L. and Mercurio, V. (1982). Cost of capital techniques used by major us firms: Survey and analysis of fortune's 1000. *Financial Management*, pp. 21–29.

Gitman, L. and Vandenberg, P. (2000). Cost of capital techniques used by major us firms: 1997 vs. 1980. *Financial Practice and Education*, vol. 10, pp. 53–68.

Graham, J. and Harvey, C. (2001). The theory and practice of corporate finance: Evidence from the field. *Journal of financial economics*, vol. 60, no. 2-3, pp. 187–243.

Guthrie, G. (2009). *Real options in theory and practice*. Oxford University Press, USA.

Hendricks, J. (1983). Capital budgeting practices including inflation adjustments: a survey. *Managerial Planning*, vol. 31, no. 4, pp. 22–28.

Herath, H., Jahera, J. and Park, C. (2001). Deciding which r&d project to fund. *Corporate Finance*, vol. 5, no. 5, pp. 33–45.

Hermes, N., Smid, P. and Yao, L. (2007). Capital budgeting practices: A comparative study of the netherlands and china. *International Business Review*, vol. 16, no. 5, pp. 630–654.

Hull, J. (2000). Futures, options and other derivatives.

Hull, J. (2009). *Options, futures and other derivatives*. Pearson Prentice Hall.

Inflation.eu (2012). Inflation south africa 2012.
Available at: `http://www.inflation.eu/inflation-rates/south-africa/historic-inflation/cpi-inflation-south-africa-2012.aspx`

Istvan, D. (1961). *Capital-expenditure decisions: How they are made in large corporations*. 33. Bureau of Business Research, Graduate School of Business, Indiana University.

Kaplan, S. and Ruback, Y. (1995). The valuation of cash flow forecast: An empirical analysis. *Journal of Finance*, vol. 50, no. 4, pp. 1059–1094.

Kelly, S. (1998). A binomial lattice approach for valuing a mining property ipo. *The Quarterly Review of Economics and Finance*, vol. 38, no. 3, pp. 693–709.

Kim, S., Crick, T. and Kim, S. (1986). Do executives practice what academics preach? *Management Accounting*, vol. 68, no. 5, pp. 49–52.

Klammer, T. (1972). Empirical evidence of the adoption of sophisticated capital budgeting techniques. *The Journal of Business*, vol. 45, no. 3, pp. 387–397.

Klammer, T. and Walker, M. (1984). The continuing increase in the use of sophisticated capital budgeting techniques. *California Management Review*, vol. 27, no. 1, pp. 137–148.

Lee, J. and Paxson, D. (2001). Valuation of r&d real american sequential exchange options. *R&D Management*, vol. 31, no. 2, pp. 191–201.

Lint, O. and Pennings, E. (2001). An option approach to the new product development process: a case study at philips electronics. *R&D Management*, vol. 31, no. 2, pp. 163–172.

Luehrman, T. (1998*a*). Investment opportunities as real options: Getting started on the numbers. *Harvard business review*, vol. 76, pp. 51–66.

Luehrman, T. (1998*b*). Strategy as a portfolio of real options. *Harvard Business Review*, vol. 76, pp. 89–101.

Madu, C. (2000). Competing through maintenance strategies. *International Journal of Quality & Reliability Management*, vol. 17, no. 9, pp. 937–949.

Malano, H., Chien, N. and Turral, H. (1999). Asset management for irrigation and drainage infrastructure–principles and case study. *Irrigation and Drainage systems*, vol. 13, no. 2, pp. 109–129.

Margrabe, W. (1978). The value of an option to exchange one asset for another. *The Journal of Finance*, vol. 33, no. 1, pp. 177–186.

Mason, S. and Merton, R. (1984). *The role of contingent claims analysis in corporate finance.* Division of Research, Graduate School of Business Administration, Harvard University.

Mathews, S., Datar, V. and Johnson, B. (2007). A practical method for valuing real options: the boeing approach. *Journal of Applied Corporate Finance*, vol. 19, no. 2, pp. 95–104.

McElroy, R. (1999). Update on national asset management initiatives: facilitating investment decision-making. In: *Innovations in Urban Infrastructure Seminar of the APWA International Public Works Congress*, pp. 1–10. Citeseer.

Miller, J. (1960). A glimpse at practice in calculating and using return on investment. *NAA Bulletin (now Management Accounting)*, pp. 65–76.

Miller, L. and Chan, S. (2002). Decision making under uncertainty - real options to the rescue? *The Engineering Economist*, vol. 47, no. 2, pp. 105–150.

Mkhize, M. and Moja, N. (2009). The application of real option valuation techniques in the cellulartelecommunication industry in south africa. *S. Afr. J. Bus. Manage. 40 (3)*.

Morton, K. (1999). Asset management in the electricity supply industry. *Power Engineering Journal*, vol. 13, no. 5, pp. 233–240.

Mun, J. (2006). *Real options analysis: Tools and techniques for valuing strategic investments and decisions*, vol. 320. Wiley.

Myers, S. (1977). Determinants of corporate borrowing. *Journal of financial economics*, vol. 5, no. 2, pp. 147–175.

Northcott, D. (1992). *Capital investment decision-making*. Cengage Learning.

Park, C. and Herath, H. (2000). Exploiting uncertainty - investment opportunities as real options: A new way of thinking in engineering economics. *The Engineering Economist*, vol. 45, no. 1, pp. 1–36.

PAS, B. (2008). 55-1: Asset management. part 1: Specification for the optimized management of physical assets. *British Standards Institution*.

Perlitz, M., Peske, T. and Schrank, R. (1999). Real options valuation: the new frontier in r&d project evaluation? *R&D Management*, vol. 29, no. 3, pp. 255–270.

Petty, J., Scott Jr, D. and Bird, M. (1975). The capital expenditure decision-making process of large corporations. *The Engineering Economist*, vol. 20, no. 3, pp. 159–172.

Pickles, E. and Smith, J. (1993). Petroleum property valuation: a binomial lattice implementation of option pricing theory. *ENERGY JOURNAL-CAMBRIDGE MA THEN CLEVELAND OH-*, vol. 14, pp. 1–1.

Pike, R. (1996). A longitudinal survey on capital budgeting practices. *Journal of Business Finance & Accounting*, vol. 23, no. 1, pp. 79–92.

Rausser, G. and Small, A. (2000). Valuing research leads: bioprospecting and the conservation of genetic resources.

Rendleman, R. and Bartter, B. (1979). Two-state option pricing. *The Journal of Finance*, vol. 34, no. 5, pp. 1093–1110.

Robichek, A. and Myers, S. (1966). Conceptual problems in the use of risk-adjusted discount rates. *The Journal of Finance*, vol. 21, no. 4, pp. 727–730.

Rose, S. (1998). Valuation of interacting real options in a tollroad infrastructure project. *The Quarterly Review of Economics and Finance*, vol. 38, no. 3, pp. 711–723.

Ryan, P. and Ryan, G. (2002). Capital budgeting practices of the fortune 1000: how have things changed? *Journal of Business and Management*, vol. 8, no. 4, pp. 355–364.

Santos, B. (1991). Justifying investments in new information technologies. *Journal of Management Information Systems*, pp. 71–89.

Schall, L., Sundem, G. and Geijsbeek, W. (1978). Survey and analysis of capital budgeting methods. *The journal of finance*, vol. 33, no. 1, pp. 281–287.

Seitz, N. and Ellison, M. (1990). *Capital budgeting and long-term financing decisions*. Dryden Press.

Shapiro, A. (2005). *Capital budgeting and investment analysis*. Prentice Hall.

Smit, H. (1997). Investment analysis of offshore concessions in the netherlands. *Financial Management*, pp. 5–17.

Steffens, P. and Douglas, E. (2007). Valuing technology investments: use real options thinking but forget real options valuation. *International Journal of Technoentrepreneurship*, vol. 1, no. 1, pp. 58–77.

Svavarsson, D. (2004). Evaluation of strategic it platform investments.

Taudes, A. (1998). Software growth options. *Journal of Management Information Systems*, pp. 165–185.

Teach, E. (2003). Will real options take root. *CFO Magazine*, vol. 19, no. 9, pp. 73–75.

Teisberg, E. (1994). An option valuation analysis of investment choices by a regulated firm. *Management Science*, pp. 535–548.

Thomas, R. (2001). Business value analysis:-coping with unruly uncertainty. *Strategy & Leadership*, vol. 29, no. 2, pp. 16–24.

Tian, Y. (1993). A modified lattice approach to option pricing. *Journal of Futures Markets*, vol. 13, no. 5, pp. 563–577.

Tiwana, A., Keil, M. and Fichman, R. (2006). Information systems project continuation in escalation situations: A real options model. *Decision Sciences*, vol. 37, no. 3, pp. 357–391.

Tiwana, A., Wang, J., Keil, M. and Ahluwalia, P. (2007). The bounded rationality bias in managerial valuation of real options: Theory and evidence from it projects*. *Decision Sciences*, vol. 38, no. 1, pp. 157–181.

Trahan, E. and Gitman, L. (1995). Bridging the theory-practice gap in corporate finance: a survey of chief financial officers. *The Quarterly Review of Economics and Finance*, vol. 35, no. 1, pp. 73–87.

Triantis, A. (2005). Realizing the potential of real options: does theory meet practice? *Journal of Applied Corporate Finance*, vol. 17, no. 2, pp. 8–16.

Triantis, A. and Borison, A. (2001). Real options: state of the practice. *Journal of Applied Corporate Finance*, vol. 14, no. 2, pp. 8–24.

Trigeorgis, L. (1988). A conceptual options framework for capital budgeting. *Advances in Futures and Options Research*, vol. 3, no. 3, pp. 145–167.

Trigeorgis, L. (1993). Real options and interactions with financial flexibility. *Financial Management*, pp. 202–224.

Tsang, A. (2002). Strategic dimensions of maintenance management. *Journal of Quality in Maintenance Engineering*, vol. 8, no. 1, pp. 7–39.

Van Putten, A. and MacMillan, I. (2004). Making real options really work. *Harvard Business Review*, vol. 82, no. 12, pp. 134–142.

Vanier, D. *et al.* (2001). Why industry needs asset management tools. *Journal of Computing in Civil Engineering*, vol. 15, no. 1, pp. 35–43.

Williams Jr, R. (1970). Industry practice in allocating capital resources. *Managerial Planning*, vol. 18, no. 6, pp. 15–22.

Wilmott, P. (1998). Derivatives.

Woodhouse, J. (2001). Asset management decision-making. 2004. *The Woodhouse Partnership Ltd.*

Woodhouse, J. (2003). Asset management: concepts & practices. *The Woodhouse Partnership Ltd.*